. INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. A-3064 DATE 10/5/81

Project Director: John Adams School/Lab TAL/WEB

Sponsor: Owens-Illinois, Inc.; Valdosta, GA

Type Agreement: P. O. # E-003-71

Award Period: From 9/8/81 To ~~11/7/81~~ ~~12/31/81~~ 1/31/82 (Performance) ______ (Reports)

Sponsor Amount: $10,850 Contracted through:

Cost Sharing: N/A GTRI/~~GIT~~

Title: The Evaluation of Boiler Capacity While Firing Pre-Dried Wood Fuel

ADMINISTRATIVE DATA

OCA Contact Leamon R. Scott

1) Sponsor Technical Contact:

Mr. Fred Kachelhafer
Owens-Illinois, Inc.
Box 1048
Valdosta, GA 31601

2) Sponsor Admin/Contractual Matters:

Mr. T. E. Neel
Purchasing Agent
Owens-Illinois, Inc.
Box 1048
Valdosta, GA 31601

Defense Priority Rating: N/A

Security Classification: N/A

RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with none proposed

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FORM OCA 4:781

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date 2/5/82

Project Title: The Evaulation of Boiler Capacity While Firing Pre-Dried Wood Fuel

Project No: A-3064

Project Director: John Adams

Sponsor: Owens-Illinois, Inc.; Valdosta, GA

Effective Termination Date: 1/31/82

Clearance of Accounting Charges: ________

Grant/Contract Closeout Actions Remaining:

- [ ] Final Invoice and Closing Documents
- [ ] Final Fiscal Report
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
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Assigned to: TAL (School/Laboratory)

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FORM OCA 10:781

A-3064

THE EVALUATION OF BOILER CAPACITY WHILE FIRING PRE-DRIED WOOD FUEL

Prepared for
OWENS-ILLINOIS, INC.
Valdosta Plant

By

John C. Adams, Jr.
James L. Walsh, Jr.

Technology Applications Laboratory
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

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Section I
EXECUTIVE SUMMARY

Tests were conducted by Georgia Tech personnel at the Owens-Illinois paper mill in Valdosta, Georgia to evaluate the performance of wood fired boilers at the plant using normal plant fuel (baseline fuel) and dried bark (Pete-Mar, Inc. fuel) supplied by Pete-Mar Incorporated of Ashburn, Georgia. The tests were conducted on September 16, 17 and 18, 1981; November 3 and 4, 1981; and November 12, 1981. The plant's Riley Boiler and Combustion Engineering Bark Boiler were each tested with baseline fuel and Pete-Mar fuel.

Boiler efficiencies were computed using a modified input-output method as specified in ASME Power Test Code 4.1 for stationary steam generating units. Output measurements and fuel input mass flow rates were taken from control room instrumentation. Fuel input heat value was obtained from laboratory analysis of fuel samples.

The test showed the following results:

1. An economic analysis was conducted to determine an approximate value for the Pete-Mar fuel. Green residue fuel is currently purchased for $11 per ton. Based on this price, the Pete-Mar, Inc. wood fuel has desirable properties that make its value approximately $15 per ton.

2. A number of efficiency and operating improvements could be realized by consultation with the boiler manufacturers. It is expected that a 5 to 10 percent increase in thermal efficiency can be realized by optimizing the existing equipment.

Section II.
INTRODUCTION

This report provides the results of a boiler test conducted at the Owens-Illinois plant in Valdosta, Georgia. The purpose of the test was to compare the performance of the two wood boilers at the plant using the standard plant wood fuel (baseline fuel) against mechanically dried bark (Pete-Mar Fuel) supplied by Pete-Mar of Ashburn, Georgia. The report includes a discussion of test objectives, procedure and results. A brief economic analysis is presented along with some general data on mechanically dried wood fuel. The report provides a set of conclusions reached through an analysis of the test results, and economic evaluation as well as general observations made by the testing team.

Pete-Mar Incorporated holds the patent on a process for mechanically drying wood. The process uses a press to remove water and compact the wood into a bale. The bale is secured with wires which can be removed with a mechanical debaler. The process not only removes water but facilitates transportation and storage of the fuel by compaction into an easily handled shape. The test provided a quantitative analysis of the performance of the fuel produced by this process in an industrial plant.

The test was performed on the plant's Combustion Engineering and Riley boilers using both the baseline and Pete-Mar fuels. Fuel sample analysis was conducted at the Solid Fuels Testing Lab of Georgia Tech. An independent evaluation of the test was conducted by the J.E. Sirrine Company as contracted by Pete-Mar, Inc. The data presented in this report reflects only the Georgia Tech analysis.

The plant also has a gas/oil fired power boiler and three black liquor fired recovery boilers. Some data was taken on these boilers to provide a complete analysis of the operating conditions at the plant during the test.

It is the author's opinion that the pulp and paper industry will find wood compression attractive in compacting wood fuel and feedstock from the forestlands only as a measure to reduce transportation costs. With the abundance of waste heat in the industry, thermal energy will continue to be a dominant force in wood fuel drying techniques.

Section III.
BOILER TEST OBJECTIVES

The fundamental purpose of the boiler tests from the position of Owens-Illinois, Inc. as percieved by Georgia Tech is to evaluate the possibility of using dry wood refuse fuels to displace current consumption of oil and gas in the powerhouse. This concept is theoretically possible in two ways. First, a displacement of oil used in the bark boilers is possible by using dry wood fuel to attain higher combustion temperatures. This also results in lower gas volumes to be handled by the boiler fans. Therefore, higher steaming rates are achieved on the wood fueled boilers without oil cofiring. Secondly, the marginal requirements of the power boiler indicates that this oil consumption may be eliminated if higher steaming rates can be maintained in the bark boilers.

This displacement of oil by the utilization of dry wood fuels can then be justified on the basis of oil cost avoidance by using dry wood fuel for steam production.

The purpose of including Georgia Tech in the tests is primarily to achieve an objective, unbiased, accurate evaluation of dry wood utilization in the C.E. and Riley boilers. The specific objectives of the dry wood boiler tests are as follows:

- o Evaluate the boiler's maximum steaming rates with the Pete-Mar wood fuel
- o Compare boiler efficiencies of existing operation with Pete-Mar fueled boiler efficiencies
- o Assess the economic attractiveness of utilizing mechanically dryed wood refuse fuel
- o Project boiler performance with wood fuels of lower moisture content than those produced mechanically (thermally dried)
- o Introduce additional background in wood fuel drying to the management of the plant

The success in meeting these objectives is only partial in that many factors (discussed later) limited the evaluation of the boiler maximum steaming rate. However, the test results are profitable in estimating these rates and observing some limitations that may be eliminated at attractive returns.

Section IV.
ASSESSMENT OF MECHANICALLY DRYED WOOD FUEL

Wood refuse fuel drying is becoming increasingly popular in the forest products industries. As previously mentioned, increased steaming rate potential is the most attractive benefit here, but the potential of decreased fuel consumption is also attractive in areas where wood fuel costs are escalating due to greater competition for this energy resource (1).

At present, thermal wood fuel drying is predominant because mechanically dried wood technology has yet to be widely proven in the market place. Each of the drying processes has advantages, but the availability of waste heat (boiler stack gases) and the relative economy of capital costs have generally favored the thermal drying systems.

Aside from capital costs, the primary consideration that must be made in selecting which apparatus offers the greatest attraction for a particular plant is the type of energy that is to be consumed in the fuel drying. Mechanical fuel drying relies almost exclusively on electrical energy while thermal drying uses waste heat or wood fueled heat. Haygreen indicates that mechanical compression drying is much more efficient than thermal drying in terms of energy input versus heating value enhancement of the wood fuel (2). However, the energy requirement is for electricity which is high quality and expensive. It is envisioned that a plant that has excess power generating capacity will find this type of fuel drying more attractive. Since the Valdosta Plant of Owens-Illinois is not in this position, it is likely that thermal drying is more attractive.

A secondary consideration that must be determined is the moisture content of the wood fuel that offers the optimum in boiler firing economics. Obviously, the lower the moisture content specified for boiler feed, the more drying energy that will be required which adversely effects project economics. Mechanical drying also has a limitation on moisture removal as compression will not yield moisture contents below about 25% (wet basis) (2). This is because the moisture contained in the wood fibers cannot be removed, practically, without thermal energy. Hydraulic pressures required to achieve notable wood drying below 35% (w.b.) are extremely high, thus maintenance for such equipment must not be overlooked. The paper by J. G. Haygreen included in Appendix B is an excellent, quantitative account of wood fuel moisture impact on boiler operation and the capabilities and limitations of compression drying.

Section V
BOILER TEST PROCEDURES

Introduction

Boiler testing was basically performed using a modified version of the ASME Power Test Code, Paragraphs 4.01-4.05. These tests utilized the steam heating output ratioed to the fuel heating input to determine the gross boiler efficiency. Efficiency data was recorded on all tests to insure that the boiler operating conditions could be related to costs. Fuel sampling was also conducted during all tests so the impact of fuel moisture and heat value could be correlated to the given boiler performance. The techniques utilized to examine the performance of the two boilers are divided into three generalized categories:

A. Efficiency Comparison
B. Maximum Steaming Rate
C. Fuel Analysis

This will be discussed in more detail below.

A. Efficiency Comparison

The input/output method of analyzing boiler efficiency was utilized for runs of conventional wood fuel feedstock and of the Pete-Mar, Inc. dried wood fuel. This offers the most direct and objective comparison of the potential benefits that can be expected for a continuous operation using dried feedstock.

The generalized equation to determine boiler efficiency for the tests is indicated below:

$$\text{(I) Gross Boiler Efficiency (\%)} = \frac{\text{Boiler Heat Output - Feedwater Heat Input}}{\text{Fuel Heat Input}} \times 100$$

Note that the simple equation excludes many variables such as induced draft and forced draft fan energy consumption in the comparison analysis. However, data on many of these constraints are recorded and must be evaluated for the justification of funds for equipment modification and addition. Additional data was also taken to record plant operational characteristics during the tests. This data gathering was simplified to include only the basic steam production information for all of the boilers so upsets in the operation of the boiler being tested could be traced to upsets in the steam distribution system. Thus, upsets in recovery boiler operation, digesting lost charges, paper machine breaks, etc. are noted when resultant upsets in bark boiler operation is observed.

The specific data used in equation (I) for efficiency calculations is found in Section VI. The numerator of equation (I) is calculated by the following equation:

Numerator = Steam Mass Output X (Average Heat Value of Steam Out - Average Heat Value of Feedwater In).

The heat values are determined from steam tables based on the temperature and pressure of these quantities. Steam mass flow is simply the steam production during the boiler testing interval taken from the steam flow integrator which is down stream of the superheater section. This gross boiler output includes steam used for soot blowers, steam turbine driven fans and pumps, etc. Also, the steam escaping out the safety valves is accounted for. This steam quantity is estimated based on the safety valve flow rating and the time the valve was open.

Fuel Heat Input is based on the equation below:

Fuel Heat Input = (Mass of Fuel to Furnace) X (Average Heating Value of the Fuel as Received)

The mass of fuel to the furnace is based on two inputs. The first input is the readout from the wood fuel feed belt weight integrator to the respective boiler and the second readout is a compensation for the fuel feed bin level change during the test interval. The C. E. Bark Boiler does not have a direct integration of the fuel flow as this value is determined from the difference of the "total wood flow to the powerhouse" integrator and the "Riley wood flow" integrator.

Boiler tests of this nature will generally result in about a 65% efficiency rating if the unit is in good operating order.

Table 1 is a summary of all the data that was taken during each of the boiler tests.

Table 1

RAW BOILER TEST DATA

	Riley Boiler	C.E. Boiler	Power Boiler	1,2,3 Recovery Boilers	Power-house
Steam Flow (1)	*	*	*	*	
Feed Water Flow (1)	*	*			
Oil/Gas Flow (1)	*	*	*		
Stack Temp. (2)	*	*			
Bark Flow (1)	*				*
Steam Temp (2)	*	*			*
Steam Pressure (2)	*	*			*
Excess O_2 (2)	*				
Feedwater Temp (2)					*
I.D. Fan Steam Flow/Amps (1,2)	*	*			
Wood Fuel Feed Bin Level (2)	*	*			
Operational Comments	*	*	*	*	*

Where possible, integrator readings are recorded instead of an instantaneous meter readout:

(1) Integrator Reading

(2) Meter Readout

Feed water temperature is not readily accessible, thus the temperature of the 50 psig steam header was utilized since it closely follows feedwater temperature. This is due to the fact that 50 psig steam is used in direct heating of boiler feedwater.

All test data relied on the accuracy of existing instrumentation. The greatest source of potential inaccuracy of data rests in the wood fuel weight belt integrators as the existing units have a tendency to overload, causing the scale not to measure the total amount of fuel to the feed bins. Careful attention was paid to the operation of the boiler fuel feed system to insure the integrity of the fuel metering. Also, numerous inspections of the weight scale mechanism were made to assure that the unit was not overloaded.

Integrator conversion factors for the raw data are indicated in Table 2.

Table 2
INTEGRATOR READING CONVERSION FACTORS

Data Collected	Output Times	Output Units
Steam Use	1000*	Pounds of Steam
Feedwater Use	1000	Pounds of Water
Gas Use	2750	SCF
Oil Use	20	Gallons of Oil
Bark Use	20	Pounds of Wood

*CE Boiler is 2000

Testing periods were restricted to a minimum of four hours of continuous boiler operation. This was agreed upon by powerhouse management because of reliability problems anticipated with the prototype debaling equipment. Since extended periods are generally run to minimize the impact of furnace bed height, it is unnecessary to accomodate this criteria because the boilers are operated essentially with a zero bed level. Also, the accuracy of the wood fuel conveyor belt scales tended to be a problem on preliminary runs because of weight range limitations.

B. Maximum Steaming Rate

The original plan for determination of maximum continuous steaming rates was to perform these runs in conjunction with the boiler efficiency tests. These "data collection" runs were to follow extended periods during which no data were collected for the operator to establish a continuous maximum rate. Due to the intermittent operation of the debaling equipment, these preliminary runs were never sufficient for the operators to stabilize all operating criteria such as combustion air, grates, and ash collection/reinjection systems.

Even with the limited continuous runs, the powerhouse operators were always attempting to produce as much steam as possible. Unfortunately, problems resulted during every attempt to operate maximum continuous rates for extended periods of time. Also, fuel feeding to the wood fuel conveyor belts made results questionable because of weight scale metering problems. However, numerous attempts at running for extended periods have been made and this data is most informative.

C. Fuel Analysis

Fuel samples were taken through an access door in the fuel feed chutes under the boiler fuel feed bins at a point immediately downstream of the feed screws. Approximately 250 grams of sample were taken every half hour. The samples were stored in sample storage bags obtained from Fisher-Scientific. The bags have zip-lock type closure which prevents losses or gains in moisture of the sample due to atmospheric conditions. Sample bags were labeled to indicate boiler, time, and date the sample was taken.

The samples were analyzed using test procedures currently under development by the American Society for Testing and Materials (ASTM). The heat values were determined using ASTM proposed test procedure E711, Standard Test Method for Gross Caloric Value of Refuse - Derived Fuel (RDF-3) using a Bomb Calorimeter. This procedure is currently under development by ASTM Committee E38 on resource recovery.

The moisture content was determined by ASTM draft standard No. 144, Test Method for Moisture Analysis of Particulate Wood Fuels, being developed by ASTM Committee E44 on solar energy conversion.

The volatile content was analyzed using ASTM draft standard No. 145, Test Method for Determination of Volatile Matter in the Analysis of Particulate Wood Fuels. The ash content was determined using ASTM Standard D1102, Standard Test Method for Ash in Wood.

The remaining parameters included the proximate analysis and fixed carbon which were determined using calculation procedures outlined in ASTM draft standard No. 169, Standard Test Methods the Determination of Combustion Characteristics of Wood Fuels. Basically, the procedure involves taking a percentage difference in weight between the moisture content, volatile content, and ash content to determine the percentage of fixed carbon.

All testing was conducted at the Georgia Tech Engineering Experiment Station's Fuel Testing Laboratory. This laboratory was established as part of a wood energy demonstration contract sponsored by the Department of Energy and was used extensively in the development of the draft standards.

Section VI
TEST RESULTS

1. Introduction

Boiler testing was conducted according to the following schedule:

Table 3
BOILER TESTING SCHEDULE

Test Run	Date (1981)	C.E. Boiler	Riley Boiler	Fuel From Wood Yard	Fuel From Pete-Mar
1.	9/16	x		x	
2.	9/17		x		x
3.	9/17		x	x	
4.	9/17		x	x	
5.	9/17		x		x
6.	9/18	x		x	
7.	9/18	x			x
8.	11/3	x		x	
9.	11/3	x			x
10.	11/4		x	x	
11.	11/12	x	x		x

Test runs 5, 8, 10 and 11 were accepted as meeting the criteria of a four hour minimum test indicative of continous operation. This shows that about an equal number of test attempts were tried on each boiler. Table 4 indicates the success rate of the individual tests. The table shows that we were unable to obtain a single maximum steaming rate test due to a variety of problems and were also unable to run numerous efficiency runs for duplication of results in the time that was alotted. However, several tests did proceed for a significant length of time and will lend themselves to comparison with the accepted test runs. Also, the information available will enable the reader to observe several interesting aspects that point out the limitations on boiler maximum continuous steaming rate.

A. Boiler Efficiency

Test runs 8, 10 and 11 offer the greatest confidence in results since these runs were performed after the mill shutdown in October at which time the fuel feed weight scales were serviced. Prior to this service call, much doubt was indicated due to the scale limitations in accurately reading fuel feed at high rates.

Table 4

BOILER TEST PROBLEMS

Test	Duration (hrs)	Maximum Continuous Rate Test	Efficiency Test	Premature Termination	Reason
1	3.25	Yes	Yes	Yes	Conveyor Belt Weight Scale
2	0.50	Yes	Yes	Yes	Conveyor Belt Weight Scale
3	0.50	Yes	Yes	Yes	Conveyor Belt Weight Scale
4	2.25	Yes	Yes	Yes	Pete-Mar and Wood Yard Fuels Mixing
5	5.25	No	Yes	No	Bark Scales Unsatisfactory
6	2.25	Yes	Yes	Yes	Conveyor Belt Weight Scale
7	0.75	Yes	Yes	Yes	Reinjection Screens Plugged
8	4.00	No	Yes	No	
9	0.75	No	Yes	Yes	Dust Collector Full
10	5.5	No	Yes	No	
11	6.25	No	Yes	No	

Utilizing the equation described in Section VI, efficiencies for the four runs were calculated as shown in Tables 5, 6, 7 and 8.

The gross efficiencies calculated from the tests are summarized below:

	Pete-Mar, Inc. Fuel	Wood Yard Fuel
C. E. Boiler	61%	52%
Riley Boiler	50%	63%

The efficiency results for the Riley Boiler show a contradictory response to utilizing dry wood fuel feed stock. The results from the C. E. Boiler test show an expected pattern for dryer wood fuels since less moisture is carried into the furnace for evaporation, flame temperature is increased improving heat transfer, and less volume of stack gasses is generated to produce unnecessary heat loss out the stack. However, the results of the Riley Boiler tests contradict this anticipated trend by indicating greater efficiency on wetter fuel.

Further analysis of the raw data indicates that substantially more steam was consumed in the Induced Draft Fan during the Pete Mar, Inc. fuel test run on the Riley Boiler. Also, the excess oxygen meter recordings indicate that almost twice as much excess oxygen was used during the Pete-Mar, Inc. fuel test run. It is the opinion of the test observers that the increased benefits of utilizing the dry wood fuel may have been negated by excess combustion air during the Pete-Mar, Inc. fuel test run. This type of problem is common with operation using a "new fuel." Based on the steam usage of the Induced Draft Fan, rough calculations show that a possible improvement to about 68% efficiency could have been achieved by reducing excess air and holding other criteria constant. The problem with efficiency on the Riley Boiler due to combustion air control is motivating example for the consideration of more sophisticated boiler controls.

The second observation made is that the efficiency results are lower than should be expected for boilers of this size. Generally, boilers of this type will continuously operate in the neighborhood of 65% thermal efficiency.

Several reasons are offered below to explain the deficit in boiler operating efficiency.

1. Excessive stack gas temperature: Similar boiler installations operate with stack temperatures in the range of $350^{o}F$ to $400^{o}F$.

Table 5

TEST No. 8
C.E. BOILER OPERATION
WOOD YARD FUEL
11/3/81

Time Interval	9:00 a.m. - 1:00 p.m.
Total Steam Output	332,000 lb Steam

Total Btu Output 332,000 lb (1454 Btu/lb - 292 Btu/lb)*** = 3.86×10^8 Btu

Total Wood Input	262,000 lb Total Integrator
	-162,000 lb Wood to Riley
2/3 (3700 ft^3) (23 lb/ft^3)*	= + 57,000 lb Feed Bin Level Change
	157,000 lb Total Boiler Feed

Total Heat Input 157,000 lb x 4720** Btu/lb = 7.41×10^8 Btu/run

Efficiency $= \dfrac{3.86 \times 10^8 \text{ Btu}}{7.41 \times 10^8 \text{ Btu}} \times 100 = 52\%$

* Bin level change times bin volume times the average bulk density of piled wood residue
** Average heating value as determined by our lab
*** Heating value of steam output minus heating value of feedwater input

Table 6

TEST No. 10
RILEY OPERATION
WOOD YARD FUEL
11/4/81

Time Interval	8:00 a.m. - 1:30 p.m.
Total Steam Output	740,000 lb Steam
	+ 4,000 lb Safety Valve*
	744,000 lb Steam Total
Total Btu Output 744,000 lb (1362 Btu/lb - 290 Btu/lb)	$= 7.98 \times 10^8$
Total Wood Input	263,000 lb Wood
	+ 0 lb Feed Bin Level Change
	263,000 lb
Total Heat Input 263,000 lb x 4818** Btu/lb	$= 1.27 \times 10^9$ Btu/run
Efficiency	$= \dfrac{7.98 \times 10^8 \text{ Btu}}{1.27 \times 10^9 \text{ Btu}} \times 100 = 63\%$

* Superheater safety valve rated at 41,402 lb/hr released for a total of 6.5 minutes
** Average heating value

Table 7

TEST No. 11
C.E. BOILER OPERATION
PETE MAR, INC. FUEL
11/12/81

Time Interval	9:45* a.m. - 3:15 p.m.
Total Steam Output	516,000 lb Steam

Total Btu Output 516,000 lb (1416 Btu/lb - 292 Btu/lb) = 5.80×10^8 Btu

Total Wood Input	350,000 lb Total
	- 235,000 lb to Riley Bin
1/2 (3700 ft^3) (23 lb/ft^3)	= + 43,000 lb Feed Bin Level
	158,000 lb of Wood Total Flow to Boiler

Total Heat Input 158,000 lb x 5989 Btu/lb = 9.46×10^8 Btu/run

Efficiency $= \dfrac{5.80 \times 10^8 \text{ Btu}}{9.46 \times 10^8 \text{ Btu}} \times 100 = 61\%$

* Steam integrator was inoperational at the beginning of run thus this portion of the test is neglected.

Table 8

TEST No. 11 (continued)
RILEY OPERATION
PETE MAR, INC. FUEL
11/12/81

Time Interval	11:00 a.m. - 3.00* p.m.
Total Steam Output	537,000 lb Integrator
	+ 5,000 lb Safety Valve**
	542,000 lb Total
Total Btu Output 542,000 lb (1344 Btu/lb - 293 Btu/lb)	= 5.70×10^8 Btu
Total Wood Input (Integrator)	154,000 lb Wood
Feed bin 1/3 (3500 ft^3) (23 lb/ft^3)	+ 26,000 lb
	180,000 lb Total
Total Heat Input 180,000 lb (6267 Btu/lb)	= 1.13×10^9 Btu
Efficiency	$= \frac{5.70 \times 10^8 \text{ Btu}}{1.13 \times 10^9 \text{ Btu}} \times 100\% = 50\%$

* Test ended at 3:00 p.m. (instead of 3:15) due to feed bin being emptied at 3:00 and wood yard stock began feeding at 3:05.

** Superheater safety valve rated at 41,000 lb/hr released for a total of 7.75 minutes

2. Furnace bed operation: High efficiency bark boilers usually operate with a given bed thickness. This allows the boiler tubes to gain maximum benefit from the radiant energy emitted from the ash bed.
3. Combustion air control: Experimentation with dividing combustion air between the grates and overfire offers greater efficiency in combustion of the wood volatiles.
4. Protection of wood fuel from precipitation will enhance the heat content during extended rainy periods.

These particular recommendations may not be appropriate for Owens-Illinois, however it is recommended that they be reviewed. Consultation with the boiler manufacturers is always a good source for innovations in existing boilers.

B. Maximum Steaming Rate

Tests 1, 4, 5, and 6 that were conducted prior to the mill shutdown offer the best evidence of maximum steaming rates. Although operation of the fuel scales in an overloaded condition did not enable an accurate comparison of boiler efficiencies, some relation to the tests after the mill shutdown indicate that efficiencies were less than optimum.

The table below shows the average steaming rates that were achieved for short durations.

Table 9

Test	Boiler	Fuel	Test Duration (hrs.)	Average Steaming Rate During Test (lb/hr)
1.	C.E.	Wood Yard	3.25	97,000
4.	Riley	Wood Yard	2.25	148,000
5.	Riley	Pete-Mar	5.25	174,000
6.	C.E.	Wood Yard	2.25	99,000

Due to the problems encountered with the fly ash collection system, extended high rates on the C.E. Boiler were unsuccessful. This is possibly attributed to the high flow rate of under fire air that can cause excessive carryover from the furnace.

To sustain steam production rates in excess of 100,000 lb/hr problems with the ash collection/reinjection system must be resolved.

From the above table one can see that Test # 5 on the Riley Boiler gives an indication that the 174,000 lb/hr steam production rate can be maintained comfortably on dried wood fuel.

From the brief tests made at high firing rates, it is believed that both boilers are able to produce a 10 to 15 percent increase in firing rate by utilizing wood fuels that have the moisture content characteristic of the Pete-Mar, Inc. dried bark. The conclusion is also supported by Haygreen (2). If the plant steam demand exists, then it is reasonable to expect the dried wood fuel to produce approximately 35,000 lb/hr of steam that would otherwise require fuel oil or gas for production.

C. Fuel Analysis

All samples taken were analyzed for moisture content. The general procedure was to dry approximately 50 grams of the sample in a drying dish for a period of 16 hours at a temperature of 103°C. The samples were then removed, weighed, and put back in the oven for two additional hours. After two hours, the samples were removed and weighed again. If the weight change was greater than 0.2% the sample was put back in the oven for two more hours. This two hour drying was continued until the weight change was less than 0.2%

The samples taken every hour were analyzed for dry basis heat value. The analysis uses an isothermal jacket bomb calorimeter to determine the dry basis heat value of the fuel. Approximately 1 gram of the sample, which has been ground and pressed into a wood pellet, is ignited in the bomb under 30 atmospheres of oxygen, and the resulting heat value determined from the rise in the water temperature of the bath in which the bomb is placed. The results of this analysis are shown in Tables 10, 11, 12, and 13. The average of the dry basis heat values is computed and this value is used for determination of the as received heat value. The standard deviation was also computed.

The as received heat value is computed using the following formula:

Heat Value (as-received) = Heat Value (dry) x (1 - moisture content/100)

The average heat value on a dry basis and the average moisture content was used to determine the as-received value. This value was used in the combustion efficiency calculations for the boilers.

Table 10

WOOD YARD FUEL MOISTURE CONTENT AND HEAT VALUE

September 17 and 18, 1981

Date	Boiler	Time	Heat Value Btu/lb Dry Basis 1st Test	2nd Test	Average	Moisture Content % by Weight
9/17	Riley Boiler	12:00 p.m.	8947	8908	8928	45.0
		12:30 p.m.	9312	9134	9223	39.6
		1:30 p.m.	*	*	*	40.0
		2:00 p.m.	9033	9029	9031	39.4
		2:30 p.m.	*	*	*	39.8
		3:00 p.m.	8950	9015	8983	40.8
		3:30 p.m.	*	*	*	38.8
9/18	C.E. Bark Boiler	8:45 a.m.	9181	8769	8975	42.4
		9:45 a.m.	9047	*	9047	43.7
		10:45 a.m.	8881	9012	8947	43.0

*Bomb test not conducted

Riley Boiler:

Heat value, dry basis Btu/lb;
Average = 9041 Standard Deviation = 130

Moisture, percent by weight as received;
Average = 45.0 Standard Deviation = 2.1

Average heat value as received, Btu/lb = 4973

C.E. Bark Boiler:

Heat value, dry basis Btu/lb;
Average = 8978 Standard Deviation =158
Moisture, percent by weight as received;
Average = 430 Standard Deviation = 0.7

Average heat value as received, Btu/lb = 5117

Table 11

PETE-MAR FUEL MOISTURE CONTENT AND HEAT VALUE

September 17 and 18, 1981

Date	Boiler	Time	Heat Value Btu/lb, Dry Basis 1st Test	2nd Test	Average	Moisture Content % by Weight
9/17	Riley Boiler	5:00 p.m.	9076	9216	9146	33.8
		5:30 p.m.	*	*	*	35.9
		6:00 p.m.	9209	*	9209	39.8
		6:30 p.m.	*	*	*	39.4
		7:00 p.m.	9156	*	9156	37.2
		7:30 p.m.	*	*	*	34.8
		8:00 p.m.	9212	*	9212	38.6
		8:30 p.m.	*	*	*	37.6
		9:00 p.m.	9386	9257	9322	36.1
		9:30 p.m.	*	*	*	36.3
		10:00 p.m.	9151	*	9151	40.7
9/18	C.E. Bark Boiler	12:00 p.m.	8948	8985	8967	35.3
		1:30 p.m.	9200	9119	9160	41.1

*Bomb test not conducted

Riley Boiler:

Heat value, dry basis Btu/lb;
Average = 9208 Standard Deviation = 91

Moisture content wet basis percent by weight as received;
Average = 37.3 Standard Deviation = 2.2

Average heat value as received, Btu/lb = 5773

C.E. Bark Boiler:

Heat value, dry basis Btu/lb;
Average = 9063 Standard Deviation = 117
Moisture content, wet basis as received percent by weight;
Average = 38.2 Standard Deviation = 4.1

Average heat value as received, Btu/lb = 5601

Table 12

WOOD YARD MOISTURE CONTENT AND HEAT VALUE
November 3 and 4, 1981

Date	Boiler	Time	Heat Value Btu/lb Dry Basis	Moisture % by Weight
11/4/81	Riley Boiler	9:30 a.m.	8751	46.0
		10:00 a.m.	*	44.4
		10:30 a.m.	9085	45.4
		11:00 a.m.	*	53.7
		11:30 a.m.	9178	51.2
		12:00 p.m.	*	46.5
		12:30 p.m.	9107	43.3
		1:00 p.m.	*	48.3
		1:30 p.m.	8740	37.9
11/3/81	C.E. Bark Boiler	9:00 a.m.	9034	51.1
		9:30 a.m.	*	49.6
		10:00 a.m.	9250	49.4
		10:30 a.m.	*	47.3
		11:00 a.m.	9099	48.0
		11:30 a.m.	*	53.4
		12:00 p.m.	9457	50.4
		12:30 p.m.	*	44.3
		1:30 p.m.	9435	47.1

*Heat value determined on an hourly basis only

Riley Boiler:

Heat value, dry basis Btu/lb;
Average = 8972 Standard Deviation = 210

Moisture content wet basis by weight as received;
Average = 46.3 Standard Deviation = 4.6

Average heat value as received, Btu/lb = 4818

C.E. Bark Boiler:

Heat value, dry basis Btu/lb;
Average = 9255 Standard Deviation = 191
Moisture percent by weight as received;
Average = 49.0 Standard Deviation = 2.6

Average heat value as received, Btu/lb= 4720

Table 13

PETE-MAR FUEL MOISTURE CONTENT AND HEAT VALUE
November 12, 1981

Date	Boiler	Time	Heat Value Btu/lb Dry Basis	Moisture % by Weight
11/12/81	Riley Boiler	11:00 a.m.	9485	36.8
		11:30 a.m.	*	34.7
		12:10 p.m.	9135	34.1
		12:30 p.m.	*	35.8
		1:00 p.m.	9283	30.2
		1:30 p.m.	*	30.4
		2:00 p.m.	8948	29.7
		2:30 p.m.	*	29.2
		3:00 p.m.	9164	26.4
11/12/81	C.E. Bark Boiler	9:00 a.m.	9401	39.8
		9:30 a.m.	*	35.2
		10:00 a.m.	9136	35.5
		10:30 a.m.	*	34.4
		11:00 a.m.	9157	36.8
		11:30 a.m.	*	35.6
		12:00 p.m.	9318	34.5
		12:30 p.m.	*	35.0
		1:00 p.m.	8996	34.1
		1:30 p.m.	*	35.1
		2:00 p.m.	9219	33.5
		2:30 p.m.	*	31.7
		3:00 p.m.	9174	33.1

*Heat value determined on an hourly basis only

Riley Boiler:

Heat value, dry basis Btu/lb;
Average = 9203 Standard Deviation = 198

Moisture, percent by weight as received;
Average = 31.9 Standard Deviation = 3.5

Average heat value as received, Btu/lb = 6267

C.E. Bark Boiler:

Heat value, dry basis Btu/lb;
Average = 9200 Standard Deviation = 131
Moisture percent by weight as received;
Average = 34.9 Standard Deviation = 1.9

Average heat value as received, Btu/lb = 5989

The remaining values in the proximate analysis, i.e. ash content, volatile content, and fixed carbon content were determined on three samples taken from each boiler test. The results of this analysis are shown in Table 14. Volatile content is determined by heating in a closed platinum crucible at 950°C without oxygen. Ash content is determined by slow heating to 600°C with oxygen.

Sample data from tests conducted on September 17 and September 18 as well as data testing conducted on November 3, 4 and 12 are presented in Tables 10, 11, 12 and 13. Although the data taken and shown in Tables 10 and 11 could not be used for efficiency calculations due to weight scale calibration difficulties, these do serve to provide data on the relative heat value and moisture content of the Pete-Mar fuel on those dates as well as that of the purchased fuel which is used by the plant. It should be noted that the baseline fuel used on November 4 and 5 was considerably more moist than the fuel used on September 17 and 18, primarily because this fuel is taken from the barking drum after the logs had traversed the flume.

The moisture content of the Pete-Mar bark during the test on November 12 was somewhat dryer than that of the tests on September 17 and 18. This was probably due to the atmospheric conditions in that the later test was conducted on a very dry, sunny day.

The heat value of the Pete-Mar fuel on a dry basis was approximately the same on September 17 and 18 and on November 12, 1981.

The data on volatile content, ash content and fixed carbon are shown in Table 14 for only the November 3, 4, and 12 tests. The ash content of the Pete-Mar fuel is slightly higher than the baseline fuel, but not enough so that there should be a noticeable difference in systems performance.

Table 14

VOLATILE, ASH AND FIXED CARBON CONTENT

Date	Fuel	Boiler	Time	Volatile Content*	Ash Content	Fixed Carbon Content*
11/4	Wood Yard	Riley Boiler	8:30 a.m.	73.73	1.96	24.31
			11:30 a.m.	75.97	1.38	22.65
			1:30 p.m.	74.85	2.65	22.50
			Average	74.85	2.00	23.15
11/3	Wood Yard	C.E. Bark Boiler	9:00 a.m.	76.02	1.37	22.61
			11:00 a.m.	75.43	1.22	23.35
			1:00 p.m.	79.68	1.27	19.05
			Average	77.04	1.29	21.67
11/12	Pete Mar	Riley Boiler	11:00 a.m.	71.47	2.51	26.02
			1:00 p.m.	72.95	2.26	24.79
			3:00 p.m.	73.05	1.71	25.24
			Average	72.49	2.16	25.35
11/12	Pete Mar	C.E. Bark Boiler	9:00 a.m.	74.14	2.02	23.84
			12:00 p.m.	71.81	2.41	25.78
			3:00 p.m.	72.72	3.03	24.25
			Average	72.89	2.49	24.62

*Percent by weight dry basis

Section VII.
ECONOMIC ANALYSIS

The economic aspects of utilizing a wood fuel dryer are similar to those of any capital equipment purchase justification. The uniqueness of energy conservation projects or more appropriately, a fossil fuel purchase reduction, lies in special tax incentives presently granted by the Federal Government. Above the usual 10% tax credit for capital investment, most energy conservation systems qualify for an additional 10% tax credit. Thus, there may be an automatic entitlement for a 20% reduction off the purchase costs of the equipment. A second criteria for project justification is the plant's evaluation of present and future gas and oil prices. These commodities which will be replaced by the higher efficiency wood fuel drying components. The present predictions of fuels costs imply more stable oil prices and rapidly escalating gas prices. This is quite the opposite of predictions two years ago. The Federal Natural Gas Deregulation Program assures that this commodity will compete head on with oil (at least in price) by 1985 and, the oil glut on the world market today suggests at least short term price stability. If fuel supply is a concern, justification can be made on anticipated production loss.

The following economic analysis is based on a number of assumptions concerning fossil fuel costs, wood fuel costs, etc. The economic attractiveness in evaluating the prospect of utilizing a wood fuel dryer lies in two principle areas:

1. Boiler Efficiency Improvement
2. Boiler Steaming Rate Increase

Boiler efficiency improvement simply means a reduction in wood fuel consumption for a given steaming rate. The data of this report indicates that both the C.E. and the Riley boilers are less efficient than expected and should profit by equipment improvements. High stack gas temperatures and other criteria suggest a thorough investigation.

Haygreen (2) indicates that a 10% reduction in fuel moisture content as seen in the Pete-Mar, Inc. fuel should translate to an increase in boiler efficiency of about 8%. The tests on the C.E. boiler support this claim. The calculations in Table 15 translate this gross efficiency increase for Owens-Illinois into an expected wood-

Table 15

Total Steam Production from wood fuels:

140,000 lb/hr Riley Boiler
90,000 lb/hr C.E. Boiler
230,000 lb/hr Total

Present Wood Consumption with 50% M.C. Green Wood

$$\text{Heat Input} = \frac{\text{Heat Output}}{\text{Boiler Efficiency}}$$

$$(\text{Wood Input Rate})(\text{Wood Unit Heat value}) = \frac{(230{,}000 \text{ lb/hr})(1100 \text{ Btu/lb})}{.65 \text{ (Optimum)}}$$

$$\text{Wood Input Rate} = \frac{(230{,}000 \text{ lb/hr})(1100 \text{ Btu/lb})}{.65\ (4800 \text{ Btu/lb})}$$

$$= 81{,}000 \text{lb/hr} = 40.5 \text{ tons/hr}$$

Wood Consumption with 10% Drier Wood Input = Same equation as above

$$= \frac{(230{,}000 \text{ lb/hr})(1100 \text{ Btu/lb})}{(.73)(6000 \text{ Btu/lb})}$$

$$= 58{,}000 \text{ lb/hr} = 29 \text{ tons/hr}$$

For a wood fuel cost of 11.00/ton, present fuel costs are $445 per hour. Ten percent dried fuel costs should be $319 per hour.

Savings = 445 $/hr - 319 $/hr = 126 $/hr.

fuel cost savings of almost $1.1 million per year. This calculation will yield an even more attractive savings, if one includes the inflation rate of existing wood fuel resources.

This economic approach may pursue another direction by evaluating how much Owens-Illinois could pay for dried wood fuel to equal present green wood cost. A simple computation will indicate that you could pay $445 per hour for 29 tons per hour of dry wood fuel (40% M.C.) yielding a unit cost of $15.34/ton. Thus, Owens-Illinois can pay 39% more for 40% moisture content fuel at an equal benefit as a standard 50% moisture content green wood.

The equations utilized in Table 15 can also be utilized to justify efficiency increases by other means as well. Possibilities such as hardware modification, and service calls from boiler manufacturers can be evaluated based on estimates of the value of boiler improvement (efficiency) due to these actions.

Capital costs of the Pete-Mar, Inc. equipment for mechanically drying wood were not provided, therefore the economic attractiveness of the system can only be speculated. In theory the energy consumed to dry the wood mechanically is far less than in thermal drying (1). But, capital costs for such equipment is at best marginal. Even though thermal drying is less efficient, utilization of waste heat such as boiler stack gases is quite attractive economically. Several papers in Appendix B will present the background for both possibilities.

Section VIII
CONCLUSIONS

1. The moisture content of the Pete-Mar fuel was not less than 30% by weight on a wet basis for any of the samples taken. Studies have indicated that wood can be mechanically dried to as low as 25%. Storage of the fuel on the uncovered pad could have raised the moisture content from 25%. This situation could possibly have been prevented with indoor storage.

2. The efficiencies measured are low for wood boilers as average efficiencies of 65% are generally expected. Consultation with the boiler manufacturers is recommended to determine possible steps to improve efficiency.

3. The Pete-Mar bark was an extremely good quality wood fuel as exhibited by a 30% increase in dry basis heat value over the baseline fuel. This difference alone will account for a 8% increase in overall boiler efficiency.

4. Stack temperatures during the test averaged 500-550^{o}F. These temperatures are more than adequate for a wood dryer system for reduction of fuel moisture content.

5. A number of ash problems were encountered with the C.E. Bark Boiler. Fuel analysis did not indicate excessive ash content. Consultation with the equipment manufacturer is again recommended.

6. Based on the reliability problems experienced with the Pete-Mar Debaler, further development is recommended before commercialization.

Section IX
REFERENCES

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2. J. G. Haygreen, "Potential for Compression Drying of Green Wood Chip Fuel," Forest Products Journal, Vol. 31, No. 8, pp 43-154

Section X

APPENDICES

Appendix A

PETE-MAR, INC. PATENT

United States Patent [19]

Strickland, Jr.

[11] 4,036,359

[45] July 19, 1977

[54] BALED WOOD CHIPS

[75] Inventor: Claudius R. Strickland, Jr., Ashburn, Va.

[73] Assignee: American Hoist & Derrick Company

[21] Appl. No.: 692,055

[22] Filed: June 2, 1976

Related U.S. Application Data

[63] Continuation of Ser. No. 431,104, Jan. 7, 1974, abandoned

[51] Int. Cl.² B65D 71/00

[52] U.S. Cl. 206/83.5; 100/37, 53/24

[58] Field of Search 206/83.5, 100/37; 53/24

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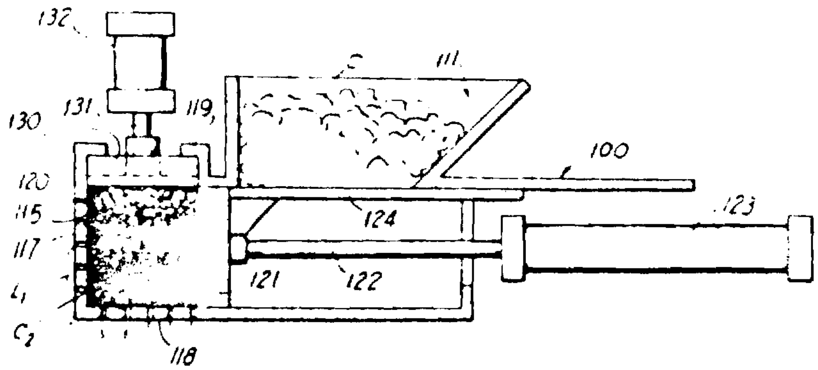
Primary Examiner—George T. Hall
Attorney, Agent, or Firm—Harvey C. Barber, Jr.

[57] ABSTRACT

A wood chip product and a process for baling wood chips in which sufficient compressive pressure is applied to a quantity of wood chips to substantially reduce its volume, and force the water liquid from the chips to create, without any binder, an adhered but separable compact mass of chips. The mass is enclosed in a flexible web cover, retained by spaced, circumferential ties which extend in the direction of compression. The chips are thus reduced to from one-half to one-sixth of their bulk or volume and have lost from about .5% to about 40% of their weight.

4 Claims, 5 Drawing Figures



BALED WOOD CHIPS

This is a continuation of application Ser. No. 431,104 filed Jan. 7, 1974.

BACKGROUND OF THE INVENTION

This invention relates to wood chips and is more particularly concerned with a wood chip product and a process of producing the same.

In the past timber, which is to be used for pulpwood, has been transported as equal length and size, debarked logs to a pulp mill where the logs were then processed into chips for further treatment to produce the cellulosic pulp fibers from which the paper was made. This, of course, entailed cutting, delimbing and debarking each tree in the field. Such an operation, to be economical, required, as a rule, the systematic growing and systematic harvesting of a single species of tree. The operation also required chipping in the pulp mill.

When land is cleared, many types and sizes of trees are cut. Therefore, such an operation does not lend itself well to the production of trees for pulp purposes. Instead, these trees are usually burned or hauled away and discarded or segregated and sold for different purposes. Recently, with the advent of the large wood chipper capable of progressively chipping whole trees including their limbs, the conversion of such trees directly into chips, on the site, has become increasingly popular. Such chips are either blown directly onto the ground or, blown, as non-compressed loose chips, into closeable truck vans for transportation to a paper mill. Such transportation, by van, is so costly that only short hauls of the chips are feasible. Indeed, even when stored in the hole of a freighter, the transportation of loose chips is presently so costly that such chips can not be economically employed by a pulp mill.

SUMMARY OF THE INVENTION

Briefly described, the present invention which reduces the difficulty described above includes producing a compacted mass of wood chips by applying pressure to the chips in one direction, generally perpendicular to the planes of the chips. In another embodiment, the compaction is applied in two directions, one essentially perpendicular to the general planes of the chips, and a second, perpendicular to the direction of first compaction.

The invention contemplates the application of sufficient pressure to exude the "water" or watery liquid from the chips but insufficient to exude any appreciable tallows, oils or tars. The resulting mass is approximately one-half to approximately one-sixth its uncompacted volume, while from about 15% to about 40% of the total weight of the chips has been forced from the chips, as "water".

With such compaction, the fibers of the wood of the contiguous chips have been implanted into each other, without the need for a binder.

The chips are then covered with a flexible web and baled with ties.

DESCRIPTION OF THE DRAWING

FIG. 1 is a side elevational view, partially broken away showing a single acting press receiving wood chips according to the present invention;

FIG. 2 is a view similar to FIG. 1 and showing the chip being compressed in a single direction;

FIG. 3 is a perspective view of a mass of compressed wood chips of the present invention, as discharged from the press of FIGS. 1 and 2;

FIG. 4 is a view similar to FIG. 3 but showing the mass of wood chips, as baled; and

FIG. 5 is a view similar to FIG. 2 but showing a double acting press in place of the single acting press.

DETAILED DESCRIPTION

In more detail the present invention includes producing wood chips using a conventional wood chipper (not shown). The entire green tree can be subjected to a chipper or simply the debarked trunk. In any event green moist chips are produced. Such chips can be produced from a large variety of wood both soft and hard, including all species of pine, oak, popular, fir, spruce, hickory, walnut, redwood, cedar, black gum, pecan and mahogany. The thickness of the raw green chip can vary up to about one inch. The lowest practical thickness of the chip is about 1/32 inch. Indeed, saw dust can be baled, using the present process, if desired. Furthermore, bark shavings from a chipper or planing mill or bark recovered from a debarker operation can be used. Thus, the term, wood chips, as used hereinafter, should be construed to include a large variety of wood from a variety of trees.

The chips are then compressed. The compressing operation includes placing the wood chips in a press, one or more sides or faces of which are movable for compacting the chips. The press should have holes or openings so that the exuded water is free to be discharged by gravity.

In FIGS. 1 and 2 a suitable single acting press 10 is depicted. This single acting press 10 includes a hopper or chute having inclined, flat, trapezoidal, downwardly converging sides, such as sides 12, 13 and 14, which are connected together by their edges to define a chute of progressively downwardly decreasing rectangular cross section. The discharge or lower end of hopper 11 communicates with the chamber 15 of the body of the press 10.

This chamber 15 is defined by spaced, opposed, complimentary, upright, rectangular, parallel, side walls, such as wall 16, the ends of which are joined by a transverse end wall 17. The bottom edges of the walls, such as wall 16, are joined by a bottom wall 18, while the top edges of the walls, such as wall 16, are joined by top wall 19. Top wall 19 is shorter than bottom wall 17 and side walls such as wall 16, and extends from the lower edge of side 12 to the upper edge of wall 17. Thus is provided a hollow, rectangular, tubular press body which is closed at its compression end, by wall 17, and is open at its opposite or ram end, having three equal length walls, such as walls 16 and 18, and a shorter wall 19. The walls 16, 17 and 18 are perforated by holes or apertures 20 at the compression end of chamber 15, so as to permit liquid to pass therefrom. One of the walls, such as walls 16, 17 and 18 or 19 is provided with a hinge (not shown) so that the compressed chips C, maybe readily removed. Extractor rams (not shown) are usually used for this purpose.

The chamber 15 receives a rectangular compression ram or piston 21 which is connected to and moved by one end of an actuator rod or shaft 22. The shaft 22 controls the piston 21 and, in turn, is extended from and retracted into a hydraulic or pneumatic cylinder 23, for moving piston 21 from its retracted non-compressing position, as shown in FIG. 1 to its compression position, as shown in FIG. 2.

Aligned with the upper edge of piston 21 and extending rearwardly therefrom, is a gate plate 24, the function of which is to close the hopper or chute 11 during the compression of the chip C to their compressed or compacted condition, as shown at C_1 in FIG. 2. Any liquid L from the compressed chips C will pass through the apertures 20 and be collected by a drain pan 25, below the compression end of the press 10.

If desired, the single acting press depicted in FIG. 1 can be converted to a double acting press 100, as depicted in FIG. 5. This press 100 is identical to the press 10 of FIG. 1 and 2 in that it has a hopper 111 having sides 112, 113 and 114, a chamber 115 defined by walls 116, 117 and 118, the walls 116, 117, and 118 being provided with holes 120 and also has a piston 121, piston shaft 122, cylinder 123 and gate plate 124.

The press 100 has an additional ram, denoted by numberal 130, which is received in top wall 119, the ram 130 being actuated by a piston rod or shaft 131 controlled by a cylinder 132.

In operation, wood chips C are loaded into hopper 11 or 111 so that the fall, by gravity, into chamber 15 or 115, as the case may be. The cylinder 23 or 123 is then actuated to extend the shaft 22 or 122, thereby causing the ram or piston to move, from right to left in FIG. 1, 2 or 5, so as to compress and compact the chips C into a compressed condition as seen at C_1 or C_2 in FIGS. 2, 3 and 5 with sufficient pressure that the water in the chips is forced therefrom.

In FIG. 5, after ram 121 has moved to its most extended position as shown in FIG. 5, the ram or piston 130 is moved downwardly to further compress the chips C_2.

As the chips C are compressed by ram 21 or 121 to chips C_1 or C_2, the clear "water" phase or liquid L or L_1, is exuded or forced from the chips through holes 20 or 120. This exuding of the liquid L_1 continues as ram 130 further compresses the chips C_2. In such an operation, it is important that the compression be carried only far enough to drive from chips C_1 or C_2, the water or clear liquid L_1 or L_2 without driving out any appreciable amount of the tallows, oils or tars, which remain in the chips. In such a compression, the ram face pressure applied by ram 21 or 121 to the chips is from 500 pounus per square inch to 5,000 pounds per square inch. This ram face pressure, however, is preferably about 1,600 pounds per square inch.

Usually the liquid L or L_1 forced from the chips constitutes from about 15% to about 50% of the total weight of the chip. After compression the chips C_1 or C_2 occupy from about one-half to about one-sixth their original volume and have from about 60% to about 85% of their previous weight. The fact that the water has been removed and the compacted chips produced does not materially effect the usefulness of the chips in a paper pulp operation.

In their compressed or compacted condition the fibres of the chips retain their integrity and are forced into intermeshment so that adjacent chips cling together.

Once in a compressed condition, the chips C_1 and C_2 do not spring back to their normal shape and size. Hence, the baling operation can be accomplished either while the chips C_1 or C_2 are under compression or after the pressure has been removed.

In FIG. 3 a mass or quantity of compacted intermeshed chips C_1 is illustrated, the mass retaining its right prism or cubicle size and shape after the pressure has been removed and the mass has been discharged.

For shipment or storage, a cover or wrapper 60, seen in FIG. 5, of burlap, polyethylene or other inexpensive flexible web material is placed around the mass of chips C_1. Also, ties, bales, straps or wire or cord hoops 61 are passed around the chips C, such ties, bales, straps, or hoops 61 being spaced from each other and extending in the direction in which the chips were compressed. In some instances, the mass of chips C, need not be covered by wrapper 60 and/or need not be baled with bales 61.

It is now seen that the chips C_1 or C_2 are in a convenient cube or right prism shape for being stored in a box car, in the hole of a ship or in a trailer for transportation to a mill. The dense condition and uniform shape permits the chips to be shipped economically over long distances.

What is claimed is:

1. A wood chip product suitable for producing paper pulp comprising a quantity of green, naturally moist wood chips in a compressed condition generally perpendicular to the general planes of said chips and having the fibres of adjacent chips intermeshed, said fibres retaining their integrity, said quantity of wood chips occupying from approximately one-half to approximately one-sixth its normal volume and having a substantially reduced quantity from its normal amount of clear liquid, therein.

2. A green naturally moist wood chip product consisting essentially of compressed wood chips from which a portion of its water has been exuded.

3. The wood chip product defined in claim 1 wherein said chips have been subjected to a pressure from one direction of from 500 pounds per square inch to 5,000 pounds per square inch and in which from about 15% to about 40% of said moisture has been removed.

4. The wood chip product defined in claim 3 including ties surrounding said wood chips.

* * * * *

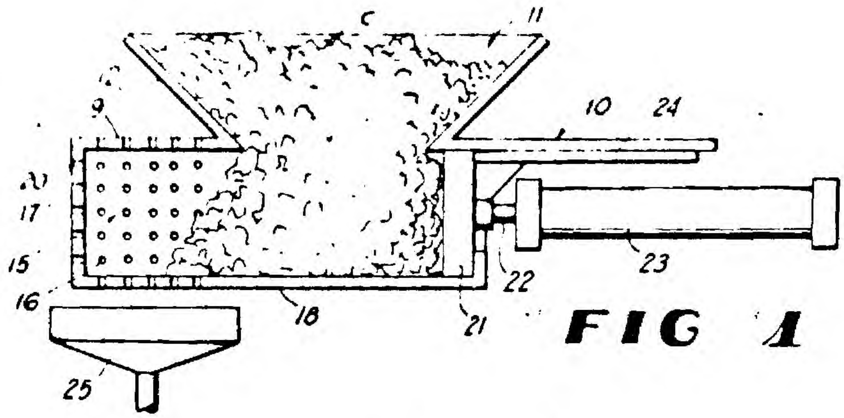


FIG 1

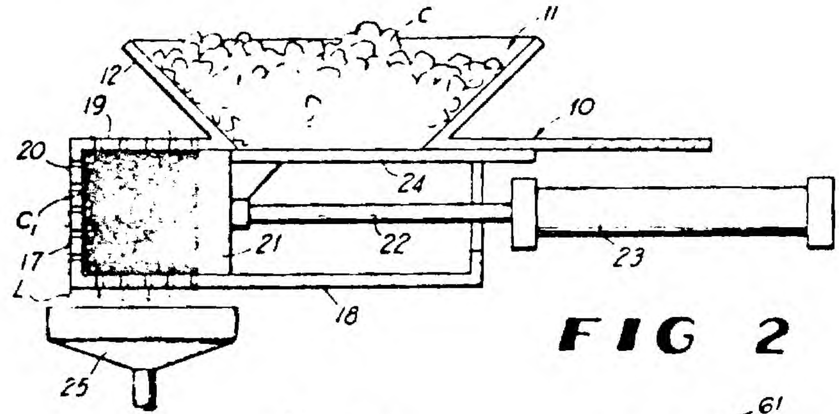


FIG 2

FIG 3

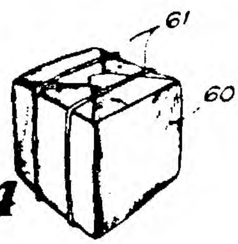


FIG 4

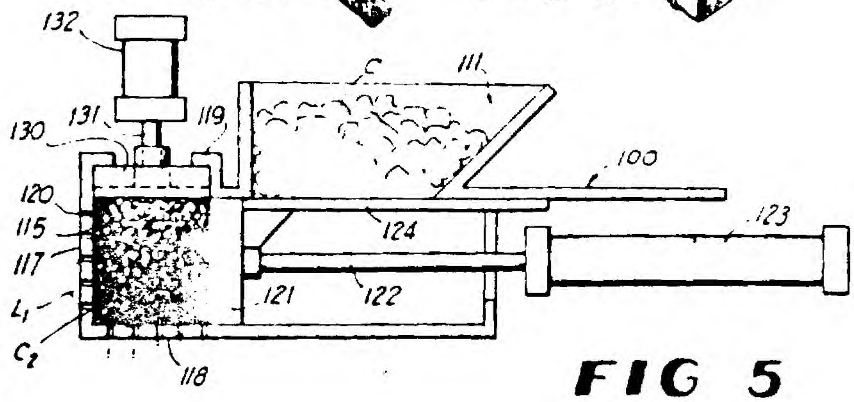


FIG 5

Appendix B

RECENT PUBLICATIONS ON WOOD FUEL DRYING

Potential for compression drying of green wood chip fuel

John G. Haygreen

Abstract

Equipment currently designed for and in use by the forest products industry for the dewatering of wood bark and chips by mechanical pressure can only reduce the moisture content (MC) to 45 or 50 percent (wet basis). Thus, this equipment is suited to remove water added in processing but not free water normally present in green wood. Exploratory research described in this paper has shown on a laboratory scale that the proper application of high pressure to green wood chips can remove the water from cell lumens, thus reducing the MC to 35 percent or less. Further, this water removal may be accomplished in an energy efficient manner. The ratio of energy increase of the fuel (increase in recoverable heat) to the mechanical energy required for water removal was found to vary from 67:1 to 240:1. This ratio depends upon wood specific gravity (SG) green MC, and mode of compression.

A theoretical relationship between volumetric compression, MC, SG, and water extracted was developed and tested on several species of softwoods and hardwoods. The cost savings for fuel and boiler investment in a hypothetical situation are presented to illustrate the economic potential of the process if production scale equipment can be developed.

Today, most of the woody biomass being used for industrial energy is in the form of mill residues, i.e., bark, sawdust, chips from trim and other waste, etc. Most of this material is partially dried as a result of normal handling and drying which occurs during the manufacturing process. In many areas of the United States only limited amounts of mill residue are still available for generation of energy. Thus, if the use of wood for industrial energy expands as expected it will be supplied primarily in the form of green fuel. This fuel will likely be produced as green whole-tree chips or green chips from cull trees and logging residue (tops and branches).

About 330 million cubic feet per year of roundwood from growing stock trees are being used today for green hog fuel. I estimate this to amount to only about 15 percent of the total volume of wood/bark now being burned as fuel. The moisture content (MC) of this green material is often significantly higher than the mill residues presently in common use. Some data regarding the green MC (GMC) of wood and bark from a variety of sources is shown in Table 1. It appears likely that in the future most hog fuel will be in excess of 80 percent MC and much of it will have an MC of at least 100 percent.

Before discussing the effects of moisture on combustion, it is desirable to review the two bases for calculating MC commonly used in the industry. Table 2 compares these two bases of calculation. On the wet basis MC is expressed as a percent of the total weight of the fuel. This basis is commonly used by chemical and combustion engineers. However, the dry basis is generally used within the solid wood and panel products industry. On the dry basis the amount of water in wood is expressed as a percent of the weight of ovendry wood.

The use of the dry basis has advantages in an analysis of wood fuels although it is not commonly used in this application. In calculations based upon the dry basis MC the total amount of fuel does not change as the fuel is dried, only the available heat per pound changes. When using the wet basis MC for analysis both the amount of fuel and the available heat per pound change as the fuel is dried. Because of its simplicity in this respect, the dry basis of MC calculation will be used throughout this paper except where noted.

One of the deterrents to the increased use of green chips for boiler fuel is the high MC. The use of wetter (green) hog fuel inherently has five disadvantages as compared to drier mill residues.

The author is Professor and Head, Dept. of Forest Prod., Univ. of Minnesota, St. Paul, MN 55108. Published as Scientific Journal Series Paper No. 11476 of the Univ. of Minnesota Agri. Expt. Sta., this work was partially supported by the Alabama Agri. Expt. Sta., Auburn Univ. It was received for publication in November 1980.

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TABLE 1. — *Moisture content of green wood.*[1]

Species	Wood type	Green MC[2] Dry basis	Wet basis
	HARDWOODS		
Aspen	Sapwood	113	53
Cottonwood	Sapwood	146	59
American elm	Sapwood	92	48
Hickory	Sapwood	62	38
Silver maple	Sapwood	97	49
Sweetgum	Sapwood	137	58
Sycamore	Sapwood	130	56
Tupelo	Sapwood	115	53
Yellow-poplar	Sapwood	106	51
Yellow-poplar	Bark	142	59
Yellow-poplar	Bark	108	52
Yellow-poplar	Total tree	104	51
S. red oak	Total tree	74	43
S. red oak	Branches	60	38
S. red oak	Stemwood	79	44
Scarlet oak	Total tree	76	43
Scarlet oak	Stemwood	80	44
N. red oak	Total tree	80	44
N. red oak	Stemwood	83	45
N. red oak	Bark	63	39
	SOFTWOODS		
Fir (grand)	Sapwood	136	58
Fir (white)	Sapwood	160	62
Hemlock, western	Sapwood	170	63
Larch, western	Sapwood	110	52
Spruce, eastern	Sapwood	128	56
Spruce, Engelmann	Sapwood	173	63
Southern yellow pines			
Loblolly	Sapwood	110	52
Slash	Total tree	84	46
Slash	Pulpwood	110	52
Slash	Branches	99	50
Slash	Bark	59	37
Longleaf	Sapwood	106	51
Shortleaf	Sapwood	122	55
Shortleaf	Total tree	103	52
Shortleaf	Pulpwood	134	57
Shortleaf	Branches	122	55
Shortleaf	Bark	78	44
Sugar pine	Sapwood	219	69

[1]Data from references (5, 6, 7, 11, 13, 15) and from Clark, A. III, and D. R. Phillips. 1979. Predicted weights and volumes of oak trees in the Tennessee Cumberland Plateau. USDA. Forest Serv. Unpublished Report.
[2]See Table 2 for a comparison of the bases.

TABLE 2. — *Equivalent moisture contents on a wet and dry basis.*

MC (wet)		MC (dry)	MC (dry)		MC (wet)
10	equals	11	10	equals	9
15		18	20		17
20		25	30		23
25		33	40		29
30		43	50		33
35		54	60		38
40		67	70		41
45		82	80		44
50		100	90		47
55		122	100		50
60		150	110		52
65		185	120		55
70		233	130		57
			140		58
			150		60

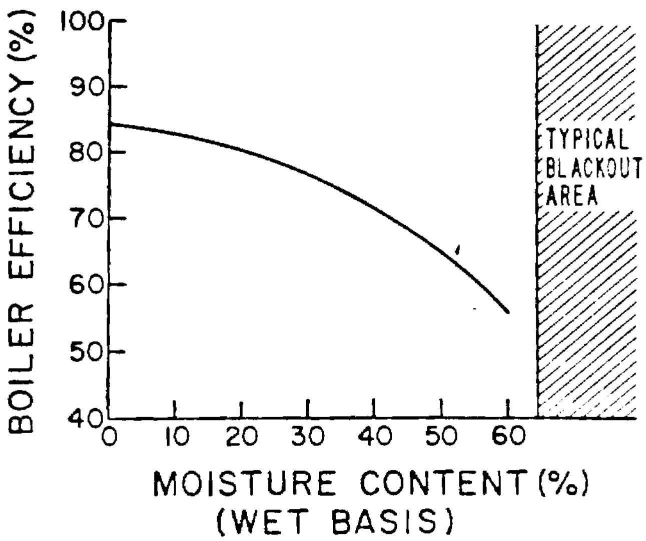

Figure 1. — Effect of fuel moisture content on boiler efficiency (14).

1. The available heat per pound of high MC fuel is less. This results from the fact that there is less dry wood substance per pound of fuel. For example, at 100 percent MC there is 0.50 pound of wood substance per pound of fuel. If the MC is reduced to 50 percent the weight of dry wood per pound of fuel is increased to 0.67 pound. It is apparent that when wood fuel is dried, the total weight of fuel decreases but the amount of wood substance per pound of fuel (and thus the available heat per pound) increases.

2. The efficiency of a boiler is lower when burning green hog fuel than when burning fuel which has been partially dried. This results primarily from the energy needed to vaporize the moisture in the wood, the first step in the combustion process. The calculated heat loss from vaporizing wood moisture to produce steam which goes up the stack at 500°F and 14.7 psi, is 1,250 Btu. Thus, for every pound of water which can be removed from the fuel by some drying process prior to combustion, the heat obtained from that fuel will be increased by 1,250 Btu (at these conditions).

This savings will range from about 1,100 to 1,300 Btu per pound of water removed, depending upon the characteristics of the boiler involved. Boiler efficiency is determined by several factors but a major one is this effect of the moisture in the fuel. The relationship is shown in Figure 1.

3. The capacity of the boiler is reduced if green fuel is used rather than partially dried fuel. The greater efficiency of the furnace (reduced wood volume) when burning dry wood and the smaller steam volume from wood moisture results in less flue gas volume. This permits an increase in the amount of wood to be fired (19).

Figure 2 shows this effect. Note that if fuel at 100 percent MC is dried to 67 percent MC the capacity of the boiler will increase by about 10 percent. Thus, in an existing installation greater steam production can be

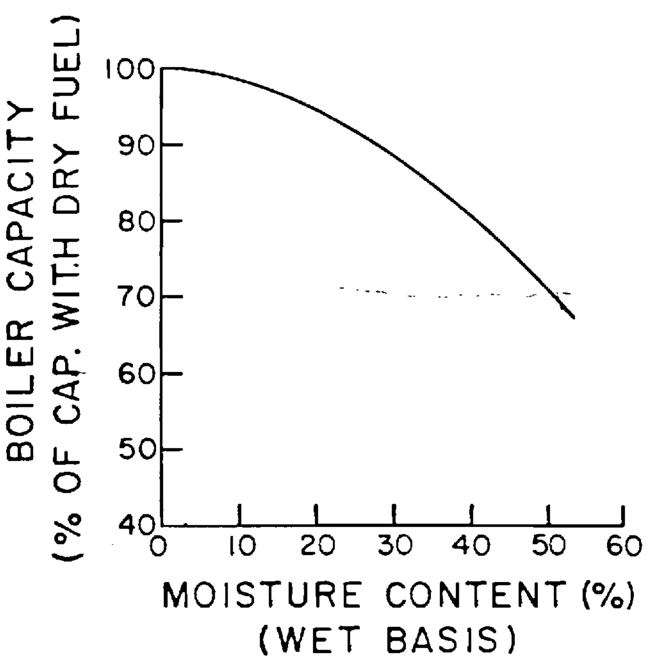

Figure 2. — Effect of fuel moisture content on hog fuel boiler capacity (16).

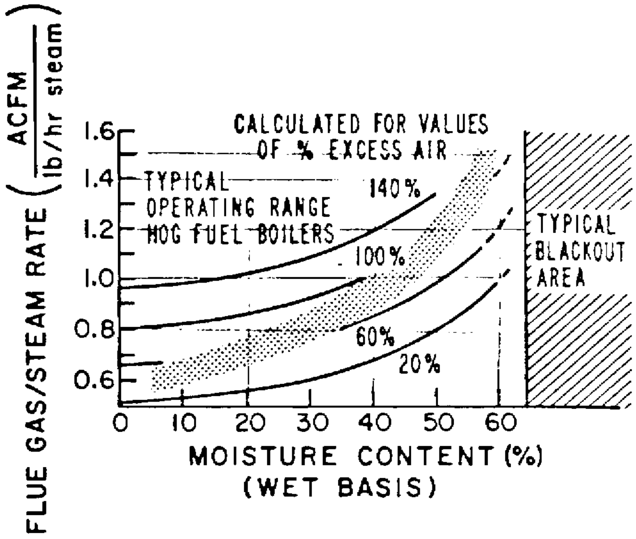

Figure 3. — Effects of fuel moisture content and excess air levels on flue gas/steam rate (14).

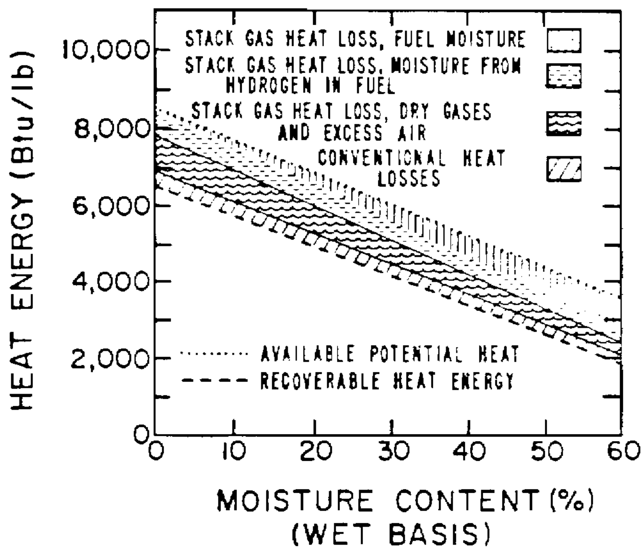

Figure 4. — Recoverable heat energy, available potential heat, and heat losses for a typical wood fuel per pound of wet fuel at various moisture contents (5).

obtained if fuels are dried rather than burned green. In a new installation designed to meet specific steam requirements, a smaller boiler can be installed if drier fuels are to be burned. Newby (9) cites a 7 percent increase in the rate of steam generation in a boiler as a result of reducing the fuel MC from 150 percent to 122 percent.

4. As fuel MC increases, the volume of stack gases generated per pound of steam produced is increased (Fig. 3). Thus, a boiler designed for a specific steam capacity using wet fuel will have higher capital and operating costs for emission control equipment than a boiler designed for dry fuel. Further, Johnson (6) shows that, in a test to evaluate the effects of fuel MC on particulate emissions, the increase of fuel MC from 108 percent to 170 percent caused a doubling of the rate of particulate emissions. Thus, drier fuels can make possible significant savings because of reductions in both the stack gas volume, which must be handled by the environmental control equipment, and the quantity of particulate emissions which must be collected.

5. A further disadvantage of wet fuels is discussed by Vanelli and Archibald (17). A conventional hog fuel boiler requires constant manual adjustment of controls with any fluctuation in fuel MC. Thus, the maximum efficiency for the boiler may not be obtained. A fuel drying system which can provide fuel at a relatively uniform MC would reduce or eliminate this problem.

The reduction in recoverable heat energy from wood as a function of fuel MC is summarized in Figure 4. This figure includes the effects of both stack gas losses and conventional losses. The decrease in available potential heat with increasing fuel MC results from use of the wet basis MC. On a dry MC basis the potential heat would remain constant regardless of MC. The ratio of the recoverable heat energy to the available potential heat (Fig. 4) is the boiler efficiency. In this figure the fuel has a higher heating value of 8,500 Btu per pound. The combustion heat recovery system is assumed to be operating with 40 percent excess air and a stack gas temperature of 500°F, fairly typical for an industrial system. A constant conventional heat loss factor of 4 percent and complete combustion are also assumed (5).

Gasification and pyrolysis processes also realize benefits from using dried wood fuels somewhat similar to direct combustion systems. The use of fuel at high MCs reduces the temperature of combustion products and efficiency of the system. In low Btu gasifiers efficiency may be lowered about 15 percent by burning green wood (16). In some gasification systems only dry wood may be used. There is little information available on the economic advantages of fuel drying systems as applied to gasification or pyrolysis.

Methods of drying

There are two approaches to the reduction of moisture in wood fuels. The first means of drying is by supplying heat energy to vaporize the moisture, i.e., by conventional drying. The second is by applying mechanical energy to squeeze the free water from the cell lumens. This might be referred to as compression drying.

The first of these approaches is the one which has received the most attention to date. It has been shown that in some situations the installation of fuel drying equipment, typically rotary drum driers, can be well justified. The source of heat energy for these driers is most often the wood residue being burned. Equipment is also available which utilizes waste heat from the stack gases (2). This equipment is widely used in Scandinavia and at least one installation is being completed in the United States. Johnson (6), Vanelli and Archibald (17), and Porter and Robinson (10) discuss the economics of evaporative driers.

The possibility of compression drying green fuel chips has been ignored to date. It should be recognized that this method has potential only for green chips. In partially dried mill residues the MC may be too low to make this process advantageous. Also, some bark and a few wood species have a GMC so low (approximately 50% to 70% MC) that this approach would result in only a slight MC reduction.

Potential

The potential application of compression drying today is to the estimated 15 percent of the industrial fuelwood currently coming from green roundwood chips. However, the amount of green wood fuel for which compression drying would be appropriate is expected to grow rapidly in the coming years.

There are a number of pieces of equipment available today which are designed to dewater pulp chips, pulping rejects, and bark. These machines are referred to as bark presses, roll presses, jaw presses, and screw presses. One machine applies pressure to bark passing between a large drum and a heavy chain.

The purpose of these presses is to remove some water from extremely wet material such as bark removed in drum barkers. The equipment manufacturers generally specify that the MC of material going into these presses should be 150 percent or higher. The MC of the output from the presses is seldom less than 100 percent although at least one manufacturer reports that 82 percent is possible.

Any compression drying system which is applicable to green wood fuel chips must be capable of greater MC reduction than possible in the presses just described. Note the GMCs shown in Table 1. Ideally, a compression drying system for green chips should be capable of reducing the MC down to 50 to 60 percent. If that were possible, a species with a GMC as low as 80 percent would gain significantly in heat value in the process.

One other type of equipment, other than the presses described above, appears to be a possible means of mechanically reducing the MC of green wood chips. In the mid-1970s there was developed (by Harris Press Division of American Hoist and Derrick) a prototype baler to increase the bulk density of pulpwood chips. The purpose of the process was to reduce the volume of chips and thus decrease handling and shipping costs. In the development of the press baling process they found it possible to reduce the original weight of softwood chips by as much as 15 percent due to moisture squeezeout. They were unable, however, to press significant amounts of water from hardwoods. Most of their tests were conducted at 900 to 1,000 psi or less.[1] The author feels that this basic baling press process, if conducted at higher pressure, is one possible approach to a viable compression drying system.

It is difficult if not impossible to remove bound water (held by physical/chemical bonding within the cell wall) by mechanical means. The weight of bound water for most species is about 30 percent of the weight of the ovendry wood. Thus, it should not be expected to lower the MC of wood below 30 percent by mechanical means. In practice it may not be possible to lower the MC to the fiber saturation point due to the fact that some small voids persist even at high mechanical pressures.

Objectives

From this background it was evident that much basic information was needed before it would be possible to analyze the technical and economic potential of compression drying of wood chips. Relationships between wood specific gravity (SG), GMC, compressive stress, volumetric compression, amount of water expelled, and energy balance of the system were basic areas of concern. In this paper I will discuss the theoretical relationships I have developed and some preliminary test results. Additional work is underway at the University of Minnesota to verify these intial findings for a wider range of species, SG, GMC, and chip geometry under different compression modes. The compression of chips mats in a pressure vessel is being included in this next phase.

Experimental procedures

Wood boiler fuel produced from green roundwood is generally in the form of wood chips — rectangular solids of varying length, width, and thickness. Before approaching the complex real problem of what happens during compression of random-sized wood chips, it was decided to study the relationships in idealized rectangular chips cut to specific dimensions, i.e., small

[1]Beeland, W. D. 1980. Personal communication. Harris Press Div., American Hoist and Derrick, Cordele, Ga.

wood blocks. From data of this simple case it should be possible to model the real situation.

For the tests reported here the blocks were cut 1 inch long (along the grain) and 1 inch wide. The thickness of the blocks was either 1/2 inch or 1 inch to simulate the thickness of whole-tree chips. The compressive stress was applied in transverse direction (radially in most cases) so as to reduce the thickness of the blocks in the way which would require the least work per unit of volume reduction. Six replications were made of the MC versus volume change tests. Tests involving MC and work relationships were replicated four times.

Species tested in this exploratory study were loblolly pine, balsam fir, red oak, sweetgum, paper birch, and yellow-poplar; major species which may find wide use as fuelwood chips in the Southern United States and in the Lake States. The wood blocks were cut from small logs containing mostly sapwood, and the GMC was often above published averages for the species.

Fundamentals of compression drying

To visualize what happens during the compression drying process it may be helpful to look at an example. Consider two species, one with a green SG of 0.30 and one with an SG of 0.50, both compressed to 50 percent of their original volume (50% volumetric compression). Figure 5 illustrates this situation; the reduction in lumen volume and the amount of water expelled. Note that the lumen in the low density wood contains 30 percent water and 70 percent air by volume when the MC is 100 percent. At the same MC, the lumen volume of the high density wood contains 73 percent water and 27 percent air. When the volume of the blocks is reduced by compression it was assumed that air and water would be expelled in the proportion originally existing in the wood. Although this assumption would be true only if internal lumen pressures were so low that compression of the included gas would be insignificant, it appears to be adequate to develop a rational preliminary model.

From Figure 5 it is apparent that there would be no advantage to compressing wood with an SG of 0.50 beyond 50 percent of its original volume since at that compression level there is little lumen volume remaining. Figure 6 shows the relationship between the amount of volumetric compression and the lumen volume which remains. The lumen volume in Figure 6 is expressed as a percent of the total original volume of the wood. Note that for wood with an SG of 0.55 (oak) all of the free water in the lumen would be expelled at 48 percent compression while wood with an SG of 0.30 (cottonwood) must be compressed 71 percent (reduced to 29% of its original volume) before all free water is expelled.

In any compression drying process it is unlikely that complete removal of the free water can be accomplished. In tests with loblolly pine, yellow-poplar, paper birch, and red oak the MC was reduced to about 31 to 35 percent at 15,000 psi. Some moisture remaining was probably free water trapped within the cell structure. The thicker the cell walls (higher the SG) the more difficult it is likely to be to remove all the free water. Results described later suggest that the design of a compression system should be based on the expectation of drying down to about 50 percent MC.

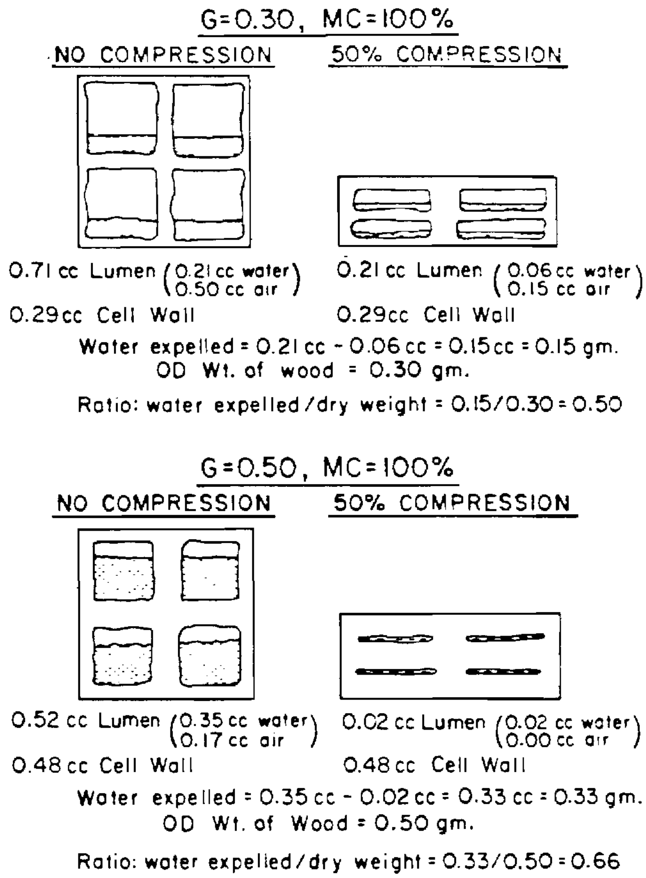

Figure 5. — Effect of compression on the water expelled from 1 cubic centimeter of a low (0.30) and a medium (0.50) specific gravity (G) wood.

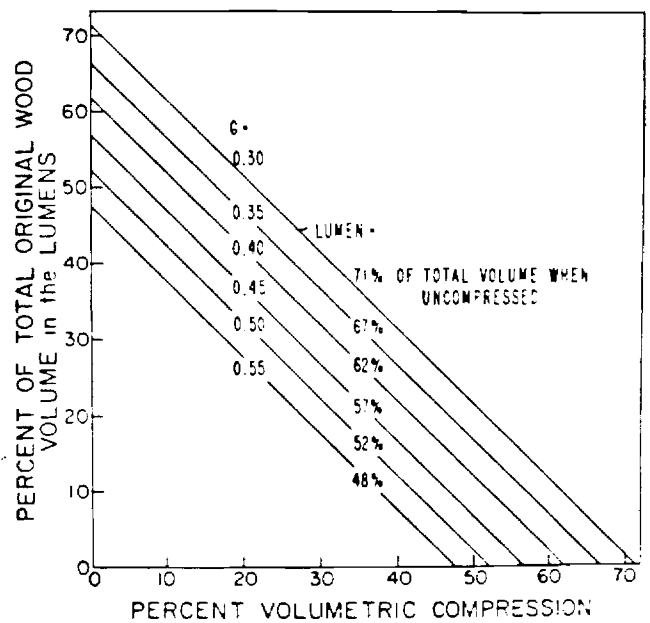

Figure 6. — Theoretical relationship between percent volumetric compression and percent of total original wood volume remaining in the lumens after compression.

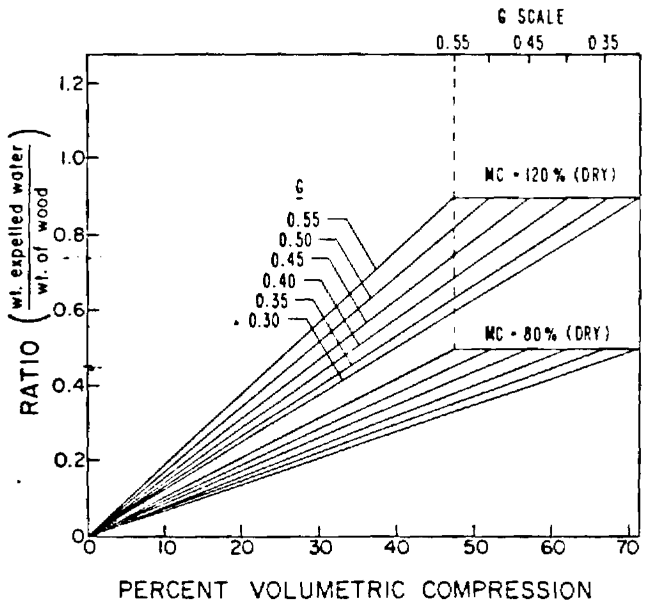

Figure 7. — Potential of compression drying: water expelled per pound of dry wood as affected by specific gravity (G) and moisture content (per Equation [1]).

Figure 7 shows how the percent of compression and initial MC affect the amount of water removed. Water removal is expressed as the ratio of the weight of water removed to the dry weight of the wood. This is based on the model suggested by Figure 5. Figure 7 shows how SG affects this relationship at 120 percent and 80 percent MC. This figure assumes no compression of the cell wall, no loss of bound water, an SG of cell wall material of 1.5, a fiber saturation point of 30 percent, an SG of bound water of 1.05, and that water and air are expelled in the ratio found in the uncompressed wood. Note that even for an original MC as low as 80 percent it may be possible to remove at least 0.4 pound of water per pound of dry wood at compression levels of 40 to 60 percent.

Accepting these assumptions, water loss expressed as a change in the percent MC can be calculated from the expression:

$$\Delta MC = -C \left(\frac{0.01\ MC - 0.30}{1 - 0.95\ SG}\right) \qquad [1]$$

Where: C = percent volumetric compression
ΔMC = change in percent MC (dry basis)
SG = specific gravity (green volume basis)
MC = percent MC of green material (dry basis)

Moisture loss predictions using Equation [1] were found to be somewhat higher than the results obtained in compression drying experiments. Figure 8 shows the experimental results for some of the tests on 1/2-inch-thick chips of 1-inch length in the grain direction. Each data point indicated in Figure 8 represents an average from three tests. The regression line shown is as computed from Equation [1]. Note that the rate of moisture loss generally follows closely with Equation [1]. Frequently, it was found that 5 to 15 percent of compression occurred prior to significant water loss. Equation [1] could be modified to provide a better estimate of moisture loss as follows:

$$\Delta MC = -(C - S) \left(\frac{0.01\ MC - 0.30}{1 - 0.95\ SG}\right) \qquad [2]$$

Where: S = the percent of compression which occurs prior to significant water loss.

It is likely that S is a function of GMC, chip geometry, and the rate of loading.

The pressure required to obtain any desired level of compression depends principally upon the SG (species) of the wood. The rate of loading and the type of compression equipment used will also have some effect on the pressure required. Initial MC should not be a significant factor since above 30 percent crushing strength is essentially constant.

Figure 9 shows typical stress-strain curves we obtained in transverse compression for loblolly pine, red oak, and yellow-poplar. These curves indicate compressive strain in thickness, not in volumetric terms. In the lower SG woods, pine and yellow-poplar, a plateau occurs during the collapse of the largest cells. This flat portion of the curve is not apparent with oak. Since moisture loss is a linear function of compression, the most energy efficient moisture reduction takes place during the flattened portion of the stress-strain curve.

The amount of work required to accomplish various compressive strain levels is shown in Figures 10 and 11 for oak, yellow-poplar, and loblolly pine. Note that the work curves for yellow-poplar and pine are nearly identical as might be expected from species with similar SGs (0.38 and 0.40). This suggests that differences in the amount of work required to accomplish crushing between hardwoods and softwoods is related principally to SG rather than to differences in cell types. Further study is needed to determine if species factors other than SG are involved in these relationships.

With samples from the same specimens as used for deriving Figures 10 and 11, the moisture loss was determined. Figures 10 and 11 show that information expressed as the change in percent MC. In these tests the initial MC of the loblolly pine and yellow-poplar was high (150% and 142%) but the green oak was at 79 percent MC. A linear regression is used to illustrate the experimentally derived moisture loss.

From work-strain curves such as Figures 10 and 11 and data collected on moisture loss it is possible to analyze the efficiency with which water can be removed. Water removal efficiency is defined here as the foot-pounds of work required to remove 1 pound of water. Using information similar to that shown in Figure 10, the water removal efficiency was calculated for pine and yellow-poplar. This is shown in Figure 12. A linear strain/moisture removal function, as verified by regression analysis, was used in this calculation. The efficiency was nearly identical in pine and yellow-poplar at the high MC level. Water removal efficiency is undoubtedly a function of initial MC and wood SG. The higher the initial MC and the lower the SG, the higher the efficiency.

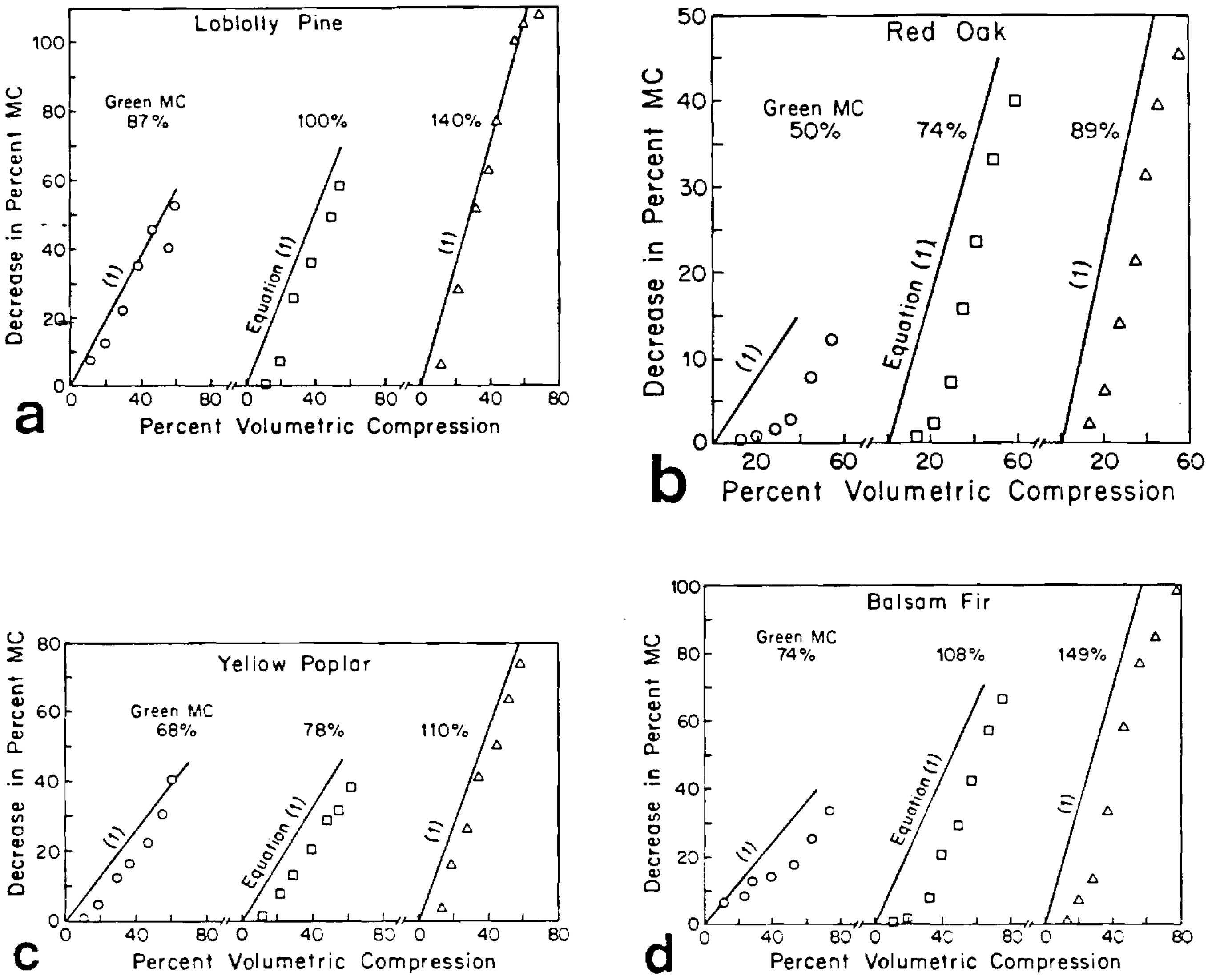

Figure 8. — Moisture loss resulting from volumetric compression of four species at three initial moisture contents.

Note in Figure 12 that at compressive strain to 65 percent only about 4,000 foot-pounds of work were required per pound of water removed. For each pound of water removed, the heating value of the fuel increases by about 1,200 Btu. The 4,000 foot-pounds used to accomplish this drying is equal to an input of only 5 Btu of energy (777.6 ft.-lb./Btu), or a ratio of 240 to 1. For red oak at 79 percent MC about 14,000 foot-pounds are required to remove each pound of water. Thus the ratio of gain in energy is 67 to 1. It seems likely that the ratio of energy gain to input for most species and initial MCs would fall between these two, i.e., between 67 and 240 to 1.

In any type of machine designed for compression drying, whether it is a screw press, roll press, or baling press, frictional and other losses would increase the work required. However, even if such losses reduce the efficiency by one-half, they would not impair the potential of compression drying in terms of energy gain versus energy input.

Possible approaches to commercialization

The extremely high ratio of energy increase to input suggests that a mechanical system designed for compression drying will not be unreasonably high in operating costs (at least the cost of power). The capital cost of equipment and the level to which the MC can be reduced will be the determining factors in the economic feasibility of such a process.

The pressures required to effectively dry wood chips in bulk are yet to be determined. The data presented earlier in this paper suggests that pressures as low as

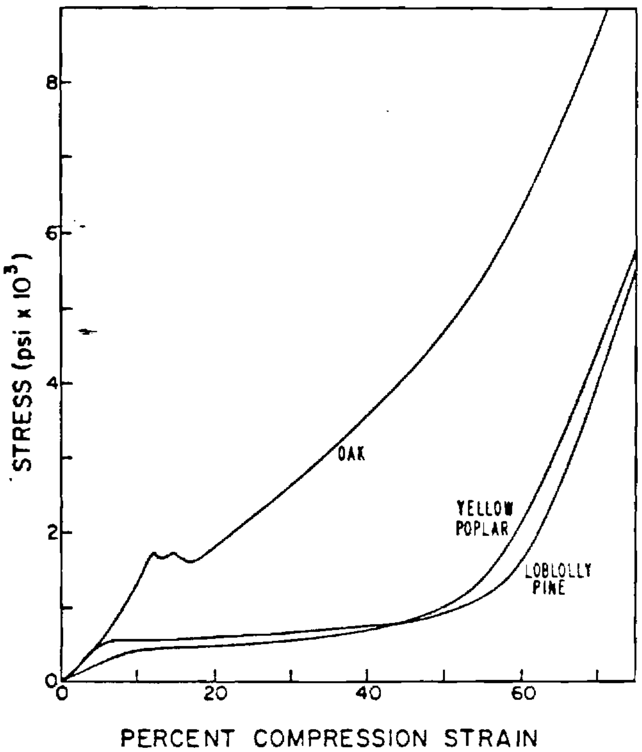

Figure 9. — Stress-strain curves of green yellow-poplar, red oak, and loblolly pine when loaded in compression perpendicular to grain (tangential).

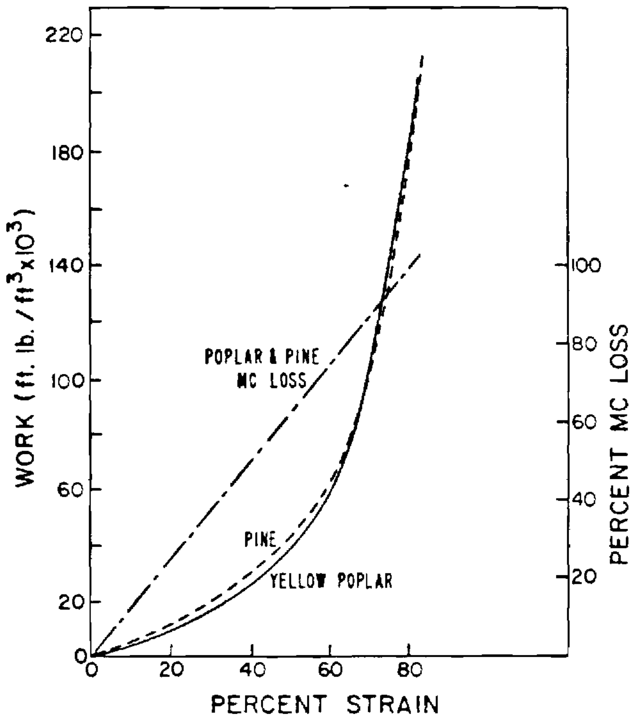

Figure 10. — Cumulative work vs. the resulting compressive strain and the loss of moisture in two species of similar specific gravity and green moisture content.

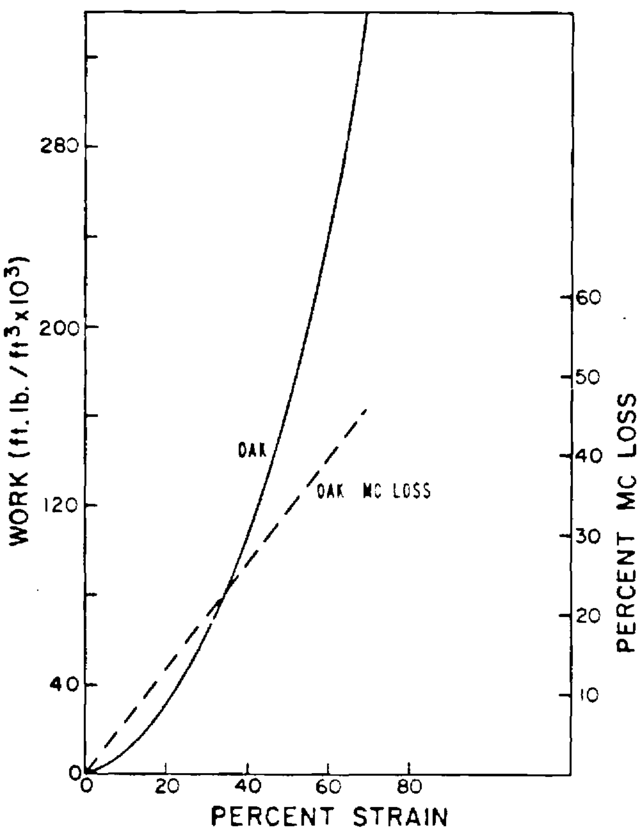

Figure 11. — Cumulative work vs. the resulting compressive strain and moisture content loss in red oak.

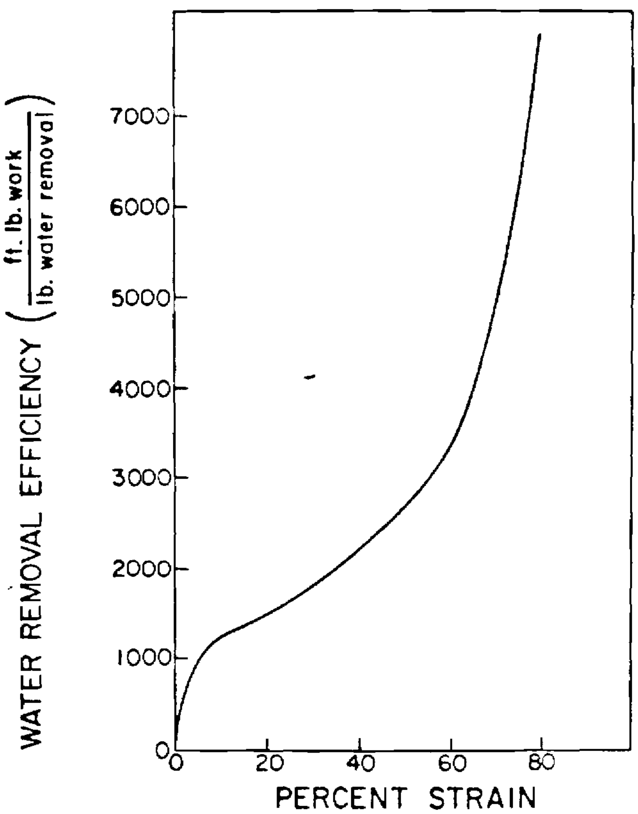

Figure 12. — Water removal efficiency in loblolly pine and yellow-poplar at high green moisture contents.

2,000 psi (Fig. 9) may produce a volumetric compression approaching 60 percent which could result in removal of up to 0.8 pound of water per dry pound of chips (at 120% MC).

However, this data is from ideal rectangular chips tested individually. In a mat of chips processed through any type of compression device there will be a distribution of internal chip pressures which may result in extensive extraction of water from some chips but little from others. This could mean that pressures as high as 5,000 to 10,000 psi may be necessary to effectively dry chips in a mat or batch process.

Tests are now being conducted in our laboratory to explore differences between compressing a chip mat and that measured for individual chips. A round compression cell with a 28-square-inch ram face area is being used in a 160-ton press. The results of these tests should provide a realistic indication of what could be accomplished in a prototype-scale press.

The types of mechanical pressing equipment now manufactured for other wood industry applications have a variety of characteristics in regard to pressure which can be exerted and mode of operation. According to information obtained from equipment manufacturers,[2] the pressure developed on wood materials passing through these machines varies from about 1,000 to 10,000 psi. One screw press (Bauer Bros.) is reported to develop pressures up to 10,000 psi. A prototype wood chip baler (Harris Press) is intended to operate at about 1,000 psi. In some roll presses (HMC Corp. and Fulton Iron Works) nip pressures of 5,000 to 7,000 pounds per lineal inch are apparently possible. A jaw press (S. W. Hooper) develops a total force of 160,000 pounds and the pressure on the chip mat appears to be about 1,000 psi. A bark press (FMP), which is a modified roll press, is reported to develop pressures up to 2,200 pounds per lineal inch. Many of these machines could be modified to operate at higher pressures if that was necessary and the expense justified.

The application of high pressure alone is not enough, however, to assure effective compression drying. Whatever mechanical system is employed, there must be a means of removing the expelled water from contact with the chips prior to release of pressure. Compressed wood chips spring back to their original volume when pressure is released. If the expelled water is still in contact with the chips when this springback occurs, a portion of the water is pulled back into the chips. In several of our experiments it was noted that at high pressures, in the range of 8,000 to 10,000 psi, crushing was so complete that springback was minimized. The effect of temperature may also be important. Springback should be studied as related to wood density, temperature, and pressure.

The necessity of removing water while the chips are under pressure suggests that some mechanisms for applying pressure may be more effective than others. In screw and baling presses there is likely to be enough lateral movement and plastic flow of the chips at high pressure that the entire mat behaves somewhat like a single piece of wood. Water expelled from one chip would then be forced out of the entire mat of chips and from the machine.

At lower pressures, however, because of inadequate wood flow within the chip mat, there would be voids or low pressure pockets which would tend to retain within the press the free water expelled from other areas. Data on the prototype baling press (Harris Press Div.) seems to substantiate this explanation. No water was expelled until pressures reached about 500 psi. It seems likely that up to that point water was migrating to zones of low pressure.

In the prototype baling press, green chips were pressed under varying conditions. Table 3 shows some of the data from these tests. Note that in some cases significant moisture loss occurred. No MC or SG information was gathered, however, so it is not possible to calculate the percent moisture loss from this data.

Figure 13 shows the compaction of a chip mat in a baler as pressure is applied. The original bulk density of the bark and wood chips was about 22 pounds per cubic foot and the final density was about 65 pounds; thus the volume was reduced to about 34 percent of the original. From these curves it might appear that only a small degree of additional compression would result from additional pressure above 900 psi. In fact, however, compression beyond the 900 psi level shown here would

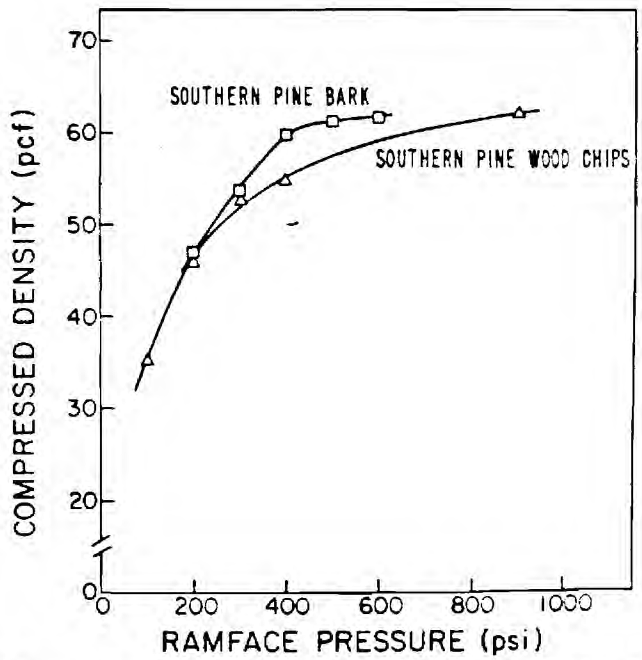

Figure 13. — Compression curves for southern pine in a baling press (see footnote 1).

[2]Addresses of these equipment manufacturers can be found in the publication *Wood Residue Energy Directory*, Forest Products Research Society, 2801 Marshall Court, Madison, WI 53705.

TABLE 3. — *Weight loss during baling of green wood chips.*[a]

Species	Chip type	Pressure	Orig. bulk density	Bale density[b]	Orig. wood wt.	Wt. of water expelled
		(psi)	(pcf)	(pcf)	(lb.)	(lb.)
Mixed hardwoods	Whole tree	900	24	45	99	none
Aspen	Debarked, 25% fines	1,400	14	32	57	none
Aspen	1 in.-3 in.	900	15	37	83	5.0
Southern yellow pine	Debarked — 1/4 in.-1in.	900	24	38	98	12.9
Southern yellow pine	Debarked — 1/4 in.-4 in.	900	20	42	81	8.2
Southern yellow pine	Debarked — 1/2 in.-2 in.	900	21	36	88	13.9
Southern yellow pine	Bark — Green	900	15	51	90	2.3
Southern yellow pine	Tops —	900	16	52	120	14.0
Southern yellow pine	Bark — dry	900	13	48	104	3.2
Mixed hardwood	1/2 in.-2 in.	900	23	35	93	5.6
Gum	Debarked	900	20	33	80	10.6

[a]Data from Harris Press Div., American Hoist and Derrick Corp.
[b]This density is after springback of the bale when pressure was released.

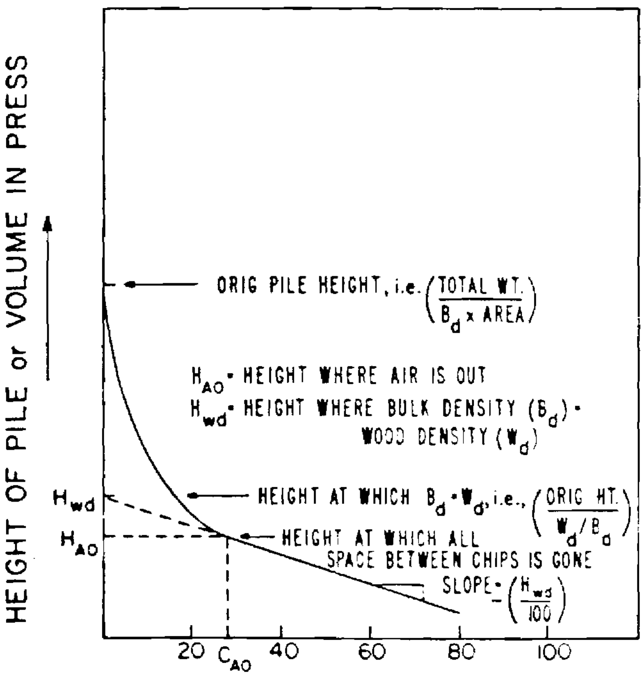

Figure 14. — Generalized curve of the volumetric compression of wood vs. height of pile of chips in press, i.e., volume within the press.

have resulted in considerable loss of water from the press even though the compression rate would have been low.

Figure 14 is proposed to explain what happens during a baling press operation. Note that the horizontal axis represents the average volumetric compression within the chips, not the reduction in total volume within the press. Initially, as pressure is applied to the chip mat and the volume in the press reduced, there is a reduction in the voids between chips and some compression of chips occurs.

During this period (shown up to 28% compression in Fig. 14) water expelled from compressed chips migrates to the voids between chips, but little if any is forced from the press. At some volumetric compression point (point H_{AO}), all the spaces between the chips are gone. Beyond that point all the reduction in volume within the press results from collapse of cell lumens; thus, the linear relationship between volume in the press and percent compression of the wood. It is during this second phase of compression (beyond C_{AO}) that most of the water will be expelled from the wood.

More research is needed before the factors affecting the efficiency of a bulk compression process (baling press or screw press) can be completely understood. Experimental data is needed to establish the general validity of the relationship proposed in Figure 14. The relationship of pressure to volumetric compression in a chip mat, as affected by SG and chip geometry, needs to be established.

Once this information is obtained, it will be possible to predict the amount of volumetric compression which can be obtained from different ram pressure as determined by wood SG and chip type. Then it will be possible to predict from the species, initial MC, and pressure the amount of water which can be expelled per unit of chips.

The removal of moisture from wood chips passing through a roll press is quite different from that in bulk pressing. Because of the rapid loading as the chip passes the nip, the stress to produce a given amount of compression will likely be higher than in a bulk press.

Furthermore, the water expelled from the chip will tend to remain in the nip or the immediate vicinity. If water is in contact when the chip comes out of the nip, it will be pulled back into the chip. Thus, for roll presses to be successfully applied to compression drying (to obtain an adequately low MC) some means must be used to remove the water expelled from the chip prior to the exit of the chip from the nip. There are several possible engineering approaches to this problem.

One other aspect of a roll press operation is critical to effective drying. Because of the high pressures which must be employed and the necessity of effective water removal, a mat of chips cannot be successfully pressed. The chips must pass the roll nip in a single layer. In this way the pressure will, because of chip geometry, be applied in the transverse grain direction.

Further, the water expelled from chips in the single layer is free to be removed by air pressure, vacuum, or absorption mats. When a mat (composed of a number of layers of chips) is passed through a roll press, as presently is done in some bark presses, the grain orientation is random, the continuity of pressure varies widely and removal of water is difficult to accomplish.

Economics of compression drying

The economic advantages of fuel-chip drying, assuming that commercial equipment to accomplish compression drying is developed, will be highly site specific. The type and operating characteristics of the boiler, the characteristics of the fuel (particularly the average MC), the air quality standards to be met, and the effectiveness of the compression drying equipment must all be considered. This would require study by a qualified engineering/consulting firm for any proposed installation. This is true for any type of fuel drying system as emphasized by numerous authorities (6, 10, 17).

Yet, it may be instructive to consider potential savings for a perhaps typical scenario. This will illustrate the general magnitude of savings which could be realized if the commercialization of compression drying is accomplished.

Assume the following situation:

1) Boiler generating 50,000 pounds of steam per hour.
2) Heat required to produce stack steam from wood moisture is 1,200 Btu/lb.
3) Green chips average 120 percent MC (54% wet basis).
4) Compression drying can reduce the MC to 67 percent MC (40% wet basis).
5) Boiler efficiency is 63 percent when operating with fuel at 120 percent MC.
6) Boiler efficiency is 72 percent when operating with fuel at 67 percent MC.
7) The higher heating value of the chips is 8,000 Btu/lb.
8) Enthalpy of generated steam is 1,120 Btu/lb.

Note that for each dry pound of wood fuel there are 1.20 pounds of moisture present at 120 percent MC and 0.67 pounds at 67 percent MC. Thus 0.53 pound (1.20 to 0.67) of water is removed in the drying process per dry pound of wood. Therefore, the usable heat per dry pound of wood is increased by 636 Btu (0.53 lb. × 1,200 Btu/lb.) as a result of the drying process. This and other factors result in the boiler efficiency increasing from 63 percent to 72 percent.

The fuel required to fire the boiler would be as follows:

$$\text{At } 120\%\, MC \frac{50{,}000 \times 1{,}120}{0.63 \times 8{,}000} = 11{,}110 \text{ dry lb./hr.}$$

$$\text{At } 67\%\, MC \frac{50{,}000 \times 1{,}120}{0.72 \times 8{,}000} = 9{,}722 \text{ dry lb./hr.}$$

Thus, there is a savings of 1,388 dry pounds of fuel per hour. This is the equivalent to 3,053 green pounds per hour of fuel at 120 percent MC. Koch (8) has projected the swathe-felling chipper can harvest chips for $18 per green ton delivered. Thus, assuming $25 per green ton for delivered chips (increased by $7.00 for stumpage and inflation), the hourly fuel savings would amount to 3,053/2,000 × $25 or $38. Operated 7,500 hours per year, the fuel savings would amount to $285,000 annually. The compression drying equipment in this example must be capable of processing 80,206 tons of green chips per year (9,722 × 2.2 × 7,500/2,000).

A capital savings also can be realized for a new installation because the capacity of the boiler would be increased, thus a smaller boiler would be required. The boiler capacity may increase by 15 percent in going from fuel at 120 percent MC to 67 percent MC (16). Package boilers typically cost $20 to $40 per pound of steam capacity.[3] Thus, a 15 percent increase in capacity in a 50,000 lb./hr. boiler could represent about a $225,000 savings in capital costs, at $30 per pound of steam capacity.

As pointed out earlier, other savings might also be realized from improved boiler control and reduced emissions control costs. However, considering only the fuel and boiler capital cost savings outlined above, there appears to be a strong economic incentive for compression drying. What remains, of course, is to develop a commercial means of compression drying which is cost effective in relation to this potential saving.

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Trees are important to Arkansas economy, recreation resources

The University of Arkansas Industrial Research and Extension Center (IREC) recently released a major study, "Forests and the Arkansas Economy," which established that trees are Arkansas' most valuable crop.

Trees provide income to Arkansas' forest land owners and raw material for the state's largest manufacturing sector — as measured by payrolls and value added in manufacturing. They help clean and renew the air, provide watershed and soil protection, and make up the state's most valuable recreational resource — its forests.

James E. Martin, president of the University of Arkansas, praised the sponsors of the study, the Ross Foundation of Arkadelphia and the Arkansas Forestry Assoc., Little Rock.

The study was developed by Frank H. Troutman, IREC, principal researcher, and Sarah G. Breshears, IREC, research associate, with John L. Green, Department of Forest Resources, UA-Monticello, and James C. Geisler, extension forester, Cooperative Extension Service.

The 83-page study notes that:

- The forest industry directly employs 51,100 workers in Arkansas with total earnings of $580,400,000 which caused expansion of economic activity in other sectors so that total employment in the state attributable to the industry reached 164,900, with total earnings of $1,830,000,000.
- The state received $14,400,000 in direct business taxes from the forest products industry in 1978. Local governments received $22,600,000 in property tax revenues from forest land owners and the forest products industry in 1978.
- The state's forests are its major recreational resource with recorded visitor days of 2,600,000 in National Forests alone. This does not include the use of forests by some 311,000 licensed resident hunters and 417,000 fishermen who generated some $131,000,000 in personal income for Arkansans. This is in addition to the $1,830,000,000 in personal income already noted.
- The forest products industry can continue to grow and it can remain Arkansas' most important manufacturing sector. Growth of the industry can result in the creation of 33,000 new jobs in direct employment and nearly 100,000 in indirect and induced employment — leading to an increase in personal income of Arkansans of nearly $1,600,000,000 in 1978 dollars by the end of this century. ■

Service provides companies with business strategies

Companies interested in learning more about the European building industry can do so through a computerized information service being offered by Battelle Memorial Institute's Geneva, Switzerland and Frankfurt, Germany divisions.

The service, known as BUILDATA, provides market information on current and future levels of building activities as well as on the demand for building products and services. Intended to assist companies in developing their European business strategies, BUILDATA may be of particular interest to suppliers of products or services to the building industry.

As part of the service, Battelle will compile building information in Belgium, France, Italy, the Netherlands, the United Kingdom, and West Germany. Information will be gathered about the current year as well as past years. Forecasts will also be made every 3 years.

Types of buildings to be analyzed include single-family houses, apartments, offices, commercial buildings, educational institutions, health care facilities, industrial complexes, and agricultural buildings.

For each building Battelle will collect information on floors, walls, roofs, windows, and doors. Service information will be gathered on heating and cooling systems, water systems, and sanitary fixtures and fittings.

The company will collect information for BUILDATA though data searches and through field interviews with architects, building contractors, manufacturers of building materials, and manufacturers' associations.

Companies may subscribe to BUILDATA for varying investments, depending on their need for data. Costs range from 1,000 to 9,000 Swiss Francs (approximately $500 to $4,500). Additional information may be obtained from Rolland B. Guy, Battelle's Columbus Laboratories, 505 King Ave., Columbus, OH 43201; 614-424-6466. ■

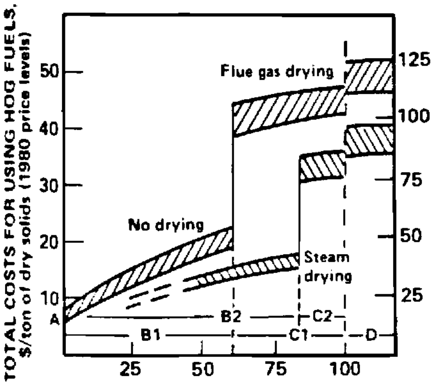
Steam drying of hog fuel

ABSTRACT
Steam drying of moist materials such as pulp and hog fuels makes it possible to recover heat for drying in the form of process steam at a pressure of 2–5 bar. Experiences from the first industrial steam dryer for pulp, in Rockhammar, Sweden, show that more than 80% of the energy is reused. Full-scale and pilot-scale test runs show the same drying economy for hog fuels. Integrating a steam dryer for hog fuel in a steam generation plant enables existing amounts of fuel to produce 25% to 35% more steam in the hog fuel boilers. Consequently, the needs and costs for external fuel (oil, gas, or hog fuel) are reduced or can in some cases be neglected. If external hog fuel, such as wood wastes, is needed as a substitute for oil, between 20% and 30% less fuel is needed if steam drying is used, compared with flue gas drying. Costs for purchasing and processing external fuel are decreased correspondingly.

KEYWORDS
Hogged fuel
Steam
Heat recovery
Wood waste

Claes Svensson
MoDo Chemetics AB, S-891 01 Örnsköldsvik, Sweden

Access to processed hog fuel will be of increasing importance to the forest industry. Not only will hog fuel be used as an energy resource, cheaper than oil or gas, but it will also be more commonly used in industry for environmental reasons (reduced landfill problems, low sulfur and ash content). But the most important aspect is that hog fuel production and processing can be controlled by the forest industry, thus guaranteeing industrial production in case of an oil shortage or a blockade. Making use of wood wastes and bark residues instead of oil has been found economical in many places already.



1. Total costs for using hog fuels in a pulp and paper mill, substituting oil with internal and external hog fuels. A: costs for disposal without heat recovery; B1: costs for steam generation from combustion of internal fuel, undried or after flue gas dryer; B2: costs for steam generation from combustion of internal fuel after steam drying; C1: costs for steam generation from combustion of external fuel after flue gas drying; C2: costs for steam generation from combustion of external fuel after steam drying; D: costs for producing pellets for marketing (external fuel is used).

However, several well-known problems can be identified concerning the use of hog fuel (wood waste, bark, sawdust, shavings, etc.): variations in fuel composition (wood and bark); variations in particle size from pieces of logs to dust; high and variable moisture content; and impurities such as sand, stones, and scrap metal.

Processing hog fuels, above all, means to homogenize the material by disintegration, screening, separating, and drying before combustion. Variations in moisture and particle size should be eliminated or reduced so that the fuel can be used most efficiently and economically in all respects.

The more extended is the use we wish to have for the hog fuel, the more processing is needed to replace oil or gas. This is shown in Fig. 1. Naturally, the more processing is needed, the less economical will the substitution appear. New techniques are necessary to increase applicability and to keep running costs at a low level.

Industrial experience

The technique of drying in superheated pressurized steam was originally developed for pulp drying by Hedström.[1]

[1]Hedström, B., U.S. patent 4,043,049 (Aug. 23, 1977).

The first industrial dryer was erected at Rockhammers Bruk, Sweden, for drying 150 tons/day of CTMP pulp. Two years of experience can now be summarized here.

Table I shows the energy balance for drying pulp. About 85% of total energy input can be recovered from the dryer. In Rockhammar, steam from the steam dryer is used for preheating the pulp suspension and for lumber and bark drying. Steam is condensed in heat exchangers without any problems (spiral- and vertical-finned tube).

The condensate has been analyzed to contain 2.5–10 g/m^3 of fibers and fragments at a pH of about 3.5–4 and to consume 0.1–0.4 BOD$_7$/m^3, depending on pulp quality.

No negative quality effects have been found after steam drying compared with conventional drying. Tests done on kraft pulp show the same quality as after air drying.

I. Heat balance for steam drying of pulp (per bone-dry ton of pulp)

Heating steam, 10 bar, ton	1.34
Generated steam, 3 bar, ton	1.00
Energy input:	
Heating steam, GJ	2.7
Electric power, GJ	0.1
Pulp, GJ	0.3
Total, GJ	3.1
Energy losses (total), GJ	0.4
Recoverable energy:	
Generated steam, GJ	2.7

II. Results from cleaning spruce bark, rough hogged

Moisture content, %	67
Initial sand and stone content (dry basis), %	7
Final sand and stone content (dry basis), %	3.4
Losses of fuel among the stones (dry basis), %	1.5

Control of final dryness is simply done by measuring the steam temperature after the cyclone and adjusting the pressure of the heating steam. It is possible to keep variations in dryness within ±0.5%.

The dryer is easy to operate and start up since only ordinary steam control equipment is used. No continuous supervision is necessary, and very little maintenance is needed.

There is no hazard of fire or explosion in the steam atmosphere. The temperature of the system is maximized by the heating steam pressure. Since there are only about 30 kg of pulp in the dryer at any time, power failure causes no problems.

Figure 2 shows the drying system at Rockhammar. Different CTMP pulps, with CSF values varying from 200 to ca. 600 ml, are dewatered from about 5% to 45–50% pulp consistency by a twin-roll press. The web is disintegrated and conveyed by a screw to the feeder of the dryer.

Pulp is continuously fed by a plug screw to the pressurized drying system. The plug is disintegrated into coarse particles which are further fluffed by a pressurized disk refiner. The fibers are then transported by superheated recirculated steam through heat exchangers as a diluted suspension. In Rockhammar, two fans located on the recirculating pipe are needed for transport.

In the heat exchangers, necessary heat for drying is supplied by heating steam condensing outside 100-mm tubes. In Rockhammar, five heat exchangers are needed for drying 6 ton/hr from 45% to 90% dryness. Each heat exchanger is 17 m long and has a shell diameter of 600 mm.

After passing through the drying ducts, dried fibers and steam are separated in a cyclone and the fibers discharged by a plug screw. Excess steam, corresponding to the increase in pulp dryness, is continuously bled off through a pressure control valve. The remaining steam is reused as transport steam. The dried discharged pulp is cooled by air before baling.

Test runs on both bark and shavings have been done in Rockhammar with the same good results as with pulp, regarding operation and heat economy. During the tests a rotary valve was used instead of the plug discharge screw.

Procedure

An extensive research program to dry different hog fuels started three years ago[2]. The object was to find and/or develop techniques for producing suitable hog fuels for combustion in existing boilers (with grates, spreader-stoker, and suspension-fired). Pulverized dry fuel can also be burned in industrial coal or oil-fired boilers and in lime kilns.

Separation of foreign material

Stones, sand, and metal pieces cause problems in every type of process equipment. Wear of conveyors, grinders, dryer, and combustion equipment is expensive because of maintenance and shutdown periods. Bark and wood wastes containing more than 1–2% grit (on a dry basis) make cleaning economical. One example of technique we have tested for cleaning consists of a vibrating screen through which air is blown in pulses. Air pulses lift the light particles several times, and vibrations transport the material on the screen. Heavy particles accumulate at the bottom (on the screen surface) and are collected separately at the discharge end of the vibrating screen. Small sand particles are withdrawn underneath the screen, and fines are separated from the air in a cyclone.

The equipment was developed for cleaning chips, and we have found the separation efficiency to vary between 50% and 90% depending on moisture content. One example of cleaning spruce bark is presented in Table II.

At 50% moisture content and with a more uniform material, as after screening, efficiency is increased to about 90%. Cleaning accepts from a screen (openings between 10 and 40 mm), where almost all the heavies are found, is one way to reduce costs for cleaning the material. Another way to reduce problems is to handle and process different fuels separately, e.g., to clean bark and wood wastes before mixing with cleaner fuel such as sawdust, shavings, or bark from debarkers.

Screening

Screening is commonly used to reduce the need for hogging capacity and to diminish the production of fines. However, screening is sometimes necessary to control maximum particle size and distribution of particles for drying and subsequent combustion.

In addition to disk screens, other types such as flip-flow screens and trommel screens have shown good performance on sticky bark and hog fuels containing fines and splinters. The continuous deformation of plastic-screen stripes keep the flip-flow screen clean. The trommel screen is cleaned by a rotating brush roll; Fig. 3 shows one example of hog fuel preparation.

Hogging and pulverizing

Several suitable disintegrators exist in the market. Low-peripheral-speed machines are widely used for rough hogging where pieces of logs can be prebroken and stones can be crushed without deterrent maintenance.

High speed machines or attrition mills are preferably used for shredding and pulverizing. With some disintegrators, problems can occur when operating on a mixture of tough, ropy bark and brittle wood.

When fairly clean fuel is handled, final disintegration can be done in the drying system, without reducing reliability substantially. Power consumption is reduced at elevated temperatures and softened material. Other advantages are reduced investment cost and space requirements and no problems handling dust-laden air evacuated from the mill.

Steam drying

Different hog fuels have been steam-dried from 70% to 5% moisture. Feed moisture content is commonly between 50% to 60%, and final dryness for pulverized fuel is 85% to 90% (15% to 10% moisture).

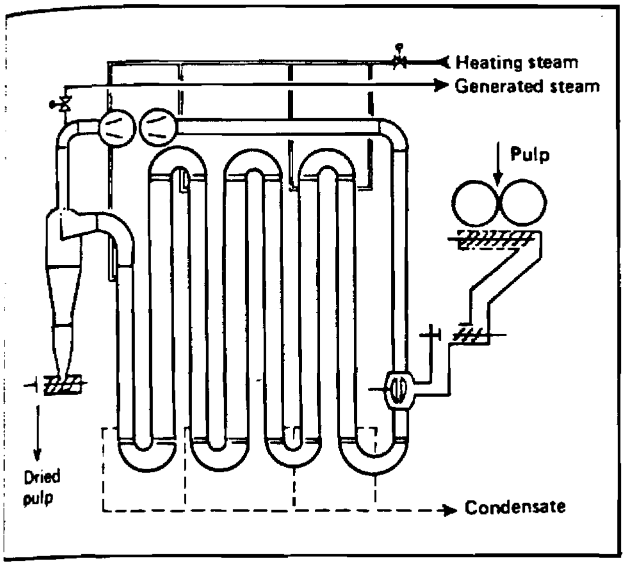
Since residence time in the dryer is short (10–20 s), control and adjustment of hog fuel flow is favorably done from a storage ahead of the dryer, thus reducing the costs and hazard of storing dried fuel. Variations in flow and moisture in the feed will cause an immediate response on the heating steam pressure in order to keep outlet dryness at a constant level.

After discharge, dry fuel can be conveyed instantaneously to the boiler or the kiln in blow pipes. Grate-fired boilers can be supplied with steam-dried fuel, according to Fig. 4. Relatively coarse particles with lower dryness will fall down to be burned on the grate. Small and very dry particles are burned in suspension.

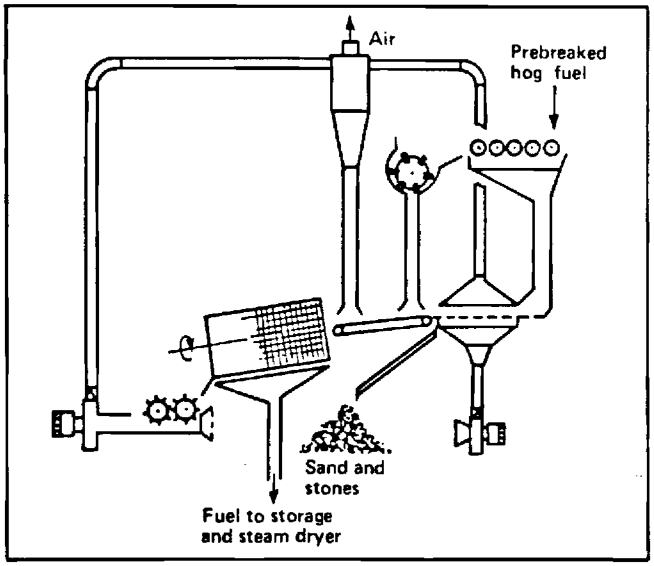
However, since combustion temperatures can be twice as high as when undried fuel is burned, cooling of the grate, changes in preheating air, etc., have to be considered in some boilers. Also, attention has to be paid to sufficient distribution of particles over the grate. Hog fuel can be introduced by a pneumatic spreader stoker or by a low-level, over-fire air system.

Pulverized fuel burnt in burners, similar to pulverized coal, permits almost the same degree of control and flexibility as using oil. A steam-drying system can be designed for the same degree of

[2] Svensson, C. *Swedish Paper Journal* 82: 281 (1979).



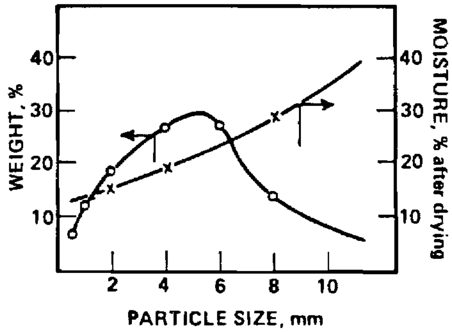
2. Steam drying system for pulp.



3. Example of preparation plant for hog fuel: disk screen, rough hogger, stone and sand separator, trommel screen, and pulverizer.

control and flexibility. Since bark and wood contain more volatile components than most coal qualities, grinding to dust is not necessary in order to keep a good flame. Particle size distribution for a pulverized fuel is shown in Fig. 5. The fuel has been produced in Rockhammar from test runs on sawmill rejects. A similar fuel has been produced from roughly hogged spruce bark too. In Fig. 5 all particles are small enough to have the same moisture content after drying (equilibrium moisture content).

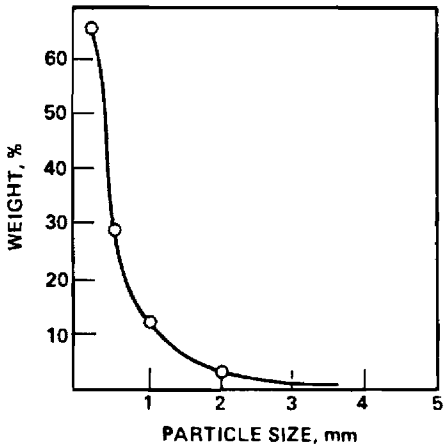
A heat balance for a steam dryer feeding a boiler is presented in Table III. In this example, bark is dried from 62% to 25% average moisture content. Heating steam has a pressure of 13 bar, and 4-bar steam is generated during drying. Steam leakage from feeder and discharger is used for preheating the bark before drying. This reduces the total heat losses from the system. Heat



4. Particle size and moisture content after steam drying bark with 62% moisture.

in the dried bark is recovered in the boiler, and heating steam condensate is reused as feedwater. Generated steam is condensed and practically used down to 70°C before leaving the mill.

Generated steam, i.e., evaporated water from hog fuel, can be used as



5. Particle size distribution for pulverized hog fuel (shavings).

process steam. Except for the possibility of producing clean steam from feedwater in a reboiler, generated steam can be used for presteaming chips, preheating and evaporation of black liquor, in steam mixers, in condensate strippers, for preheating air for combustion and drying, etc.

Predrying hog fuel can sometimes be economical, making use of generated steam. Separation of grit can be improved, and at the same time power consumption for grinding and heating steam consumption is reduced.

Drying hog-fuel generated steam contains less dust than from pulp drying. However, depending on the type of hog fuel, some chemicals, such as turpentine, formic acid, and acetic acid, contaminate the steam. These substances can economically be recovered or burned after the steam has been condensed. Results from analysis of the condensate are disclosed in Table IV. One can calculate, from the COD results, that about 0.2–0.5% of the fuel has been vaporized during steam drying. Com-

III. Heat balance for steam drying bark from 38% to 75% dryness

	Heat, kJ/kg dry solids		
	Input	*Theoretical 0° C*	*Down to 70° C*
Heat input:			
Moist bark, 10° C	80		
Heating steam, 13 bar	3900 (latent)		
Electrical energy	110		
Total	4090		
Heat recovered:			
Dried bark, 140° C		400	400
Generated steam, 4 bar		3500	3120
Total		3900	3520
Heat losses:			
Radiation		190	190
Generated steam condensate		0	380
Total		190	570

pared with total BOD_7 from a kraft mill, this condensate, uncleaned, can cause an increase in total BOD of a few percentage points.

Comparison to flue-gas drying

Taking the example from Table III, total heat losses for steam drying are about 0.6 GJ/ ton of dry matter. This is equivalent to the heat generated from about 30 kg of dry matter, assuming a heat value of 20 GJ/ ton of dry matter.

The corresponding figures for flue-gas drying are calculated to 4.5 GJ/ ton of dry matter and about 250 kg, assuming the exhaust gas temperature from the dryer to be 100°C. From these calculations it can be shown that a flue-gas dryer can only be economical (from an energy point of view) compared with no drying at all, if the boiler efficiency is increased by about 3%, by making use of less excess air, and/or by lowering exhaust gas temperature when dry fuel is used.

Economy

In discussing economy by replacing oil or gas with hog fuels, many different situations can occur regarding:

- Local oil or gas (coal) prices.
- Accessibility to hog fuels of different qualities. Lack of hog fuel or high prices seems to make steam dryer economy superior. To harvest, collect, transport, and process external fuel is expensive, and these costs can be decreased substantially by steam drying compared with other available solutions.
- The fact that an existing boiler can produce about 30% more net heat if available hog fuel is steam dried. The capacity of some boilers can be improved by 100% (with increased fuel consumption), thus eliminating capital investment for a new boiler.
- Possibilities of selling a first class hog fuel at a high price, probably after pelletizing.

IV. Condensate analysis from steam drying hog fuels

	Spruce bark	Spruce wood	Peat
pH	3.5	4.5−5	4.5
BOD_7, kg/m^3	0.8−1.4	0.6	0.2
COD, kg/m^3	1.9−2.2	0.9	0.4

Two examples of calculating steam drying economy will be presented here.

1. Hog fuel (woodwaste) is available as "green chips" on mill site at a cost of \$20/ ton at 55% moisture. Steam should be produced at a rate of 100 ton/hr from combustion of dried hog fuel.

The price for chipped wood waste corresponds to an oil price of about \$100/m^3 (\$16/barrel). Using flue-gas drying, 24% more hog fuel is needed compared with steam drying, in this case 5 tons of dry matter or about 11 tons of green material/hr. Assuming the same installation and operating costs, steam drying generates an annual saving of about \$1,800,000/year, compared with flue-gas drying.

Of course, differences in applicability, flexibility, and maintenance exist between different systems, which have to be evaluated in a more detailed study.

2. A limited amount of bark, 10 tons of dry matter/ hr, should replace oil as efficiently as possible. The oil price is \$200/ m^3 (\$32/ barrel), and the price of electrical power is \$50/MW·hr. Payoff time for steam drying is calculated.

Dry hog fuel (in this case bark) produces about 6.2 tons of steam/ton of d matter in the boiler. With undried ba at an average moisture content of 6 only about 4.0 tons/ton of dry mat can be generated. Steam is genera from oil at a cost of \$17/ton of stea based on the oil price.

If, therefore, 10 tons of bark (d basis) is steam dried, 22 additional t of steam from bark can be genera per hour, reducing the cost for oil in t boiler by \$370/hr or about \$3,142,0 year.

Table V shows calculation of pay time for preparation and steam dryi of bark. Although this example de with a relatively small capacity, it sho good profitability.

V. Payoff time calculation

Gross saving, \$/year	3,142,0
Power costs for drying and preparation, \$/year	−230,0
Loss of power generation compared with steam generated from oil, \$/year	−440,0
Supervision, \$/year	−70,0
Maintenance, \$/year	−190,0
Net saving, \$/year	2,212,0
Investment needed, \$	3,500,0
Payoff time, years	approx. 1.

Based on a paper published in *1980 Pulp Conference Proceedings*, a TAPPI PRESS pu cation.

IMPROVED BARK BOILER EFFICIENCY AND CAPACITY BY THE UTILIZATION OF THE FLUE GAS FOR PRE-DRYING

Bo C. Ferm
Bahco Systems, Inc.
Atlanta, Georgia

ABSTRACT

An average of 25-40% of the bark moisture can be removed ahead of the furnace by the utilization of the flue gas from the boiler for pre-drying. The result will depend on the actual gas temperature and the available amount of flue gas.

Because of the lower temperature of the gas leaving the system boiler and drier, more steam will be generated from each unit of bark. As less water must be evaporated from the bark in the furnace, the boiler capacity will increase 15 to 40%.

Improved utilization of bark as a fuel means that all available bark and wood waste is burned with a minimum of loss. The losses can be divided into material losses and energy losses from the combustion equipment.

Material losses that occur in the log yard, very often up to 20%, cannot be ignored either as a fuel or a pollutant. Combustion losses dominated by the flue gas losses are of the greatest importance when they are related to boiler efficiency.

UTILIZATION OF LOG YARD WASTE AS A FUEL

Log yard waste and purchased bark contain stones and other material that must be removed before the bark can be used as a fuel. In (9) nine Scandinavian mills an air classifier system shown in Figure 1. is being utilized for the purpose of removing heavy material from the bark.

The material is transported by belt conveyors to the classifier and ahead of the equipment the material is unloaded at a 90° angle. At this point, a roller catches logs and other tall material and discharges them from the system. Upon reaching the classifier the material is winnowed by a transverse air stream. Because of its high weight to size ratio, the trash falls down into a reject hopper while the acceptable material is transported by the air stream into an accept hopper. The evacuated air is cleaned in a cyclone and the dust collected is handled together with the clean bark and transferred to the normal bark handling system.

During a 48 hour test completed at one of the installations, the following results were obtained:

Main Balance	
Waste to the classifier	256 m^3 (9041 cu ft)
Accepted material	249 m^3 (8793 cu ft)
Rejected Material	7 m^3 (247 cu ft)
Reject Analyzation	
Earth, stone, sand	3.5 m^3 (124 cu ft)
Bark, log pieces	3.5 m^3 (124 cu ft)

The weight of the earth, stones and sand rejected was 5 m. ton (11,023 lb.). It also must be pointed out that the average capacity of a plant is 100m^3/h (3,532 cu. ft./hr.).

ENERGY LOSSES AT COMBUSTION

There are a number of ways to describe the heat value of bark. A very simple method is to substract all losses from the gross heat value resulting in the real heat flow from the boiler. Energy is supplied mainly in the form of fuel and feedwater. The boiler converts it to steam, uncombusted ash, convection losses and hot flue gas. A calculation of the net heat value of bark from the gross heat value can consequently be divided into the following categories: (See figure number 2.)

1. Evaporation of formed water depending on fuel hydrogen content.
2. Evaporation of bark moisture.
3. Heating of the formed water vapor to flue gas temperature.
4. Heating of dry flue gas to flue gas temperature.
5. Convection losses to the room outside the boiler.
6. Uncombusted ash.

Of those listed, two categories cannot be controlled and have little importance - namely the formation of water out of hydrogen and the losses to the room outside the boiler. By pressing, it is possible to limit the moisture content in the bark to 58-60% in an inexpensive way, but a lot of water remains when the material reaches the boiler house. Another way to remove water is to treat the waste in a drier. However, if supplementary fuel including bark is used, nothing is done to improve the heat out put as the amount of heat needed for the evaporation of water is the same, and high grade fuel has been used. If drying influences the amount of heat generated from a certain amount of bark, the energy used must be waste energy that cannot be used to produce steam. This kind of waste energy can be found in the boiler itself---the flue gas heat.

The flue gas loss consists of the evaporated water and the dry flue gas heated to the actual temperature and its dependence of specific flue gas amount (dry flue gas per unit bone dry fuel) and temperature is shown in figure 3. The utilization of the entire flue gas for pre-drying the fuel will decrease the loss through the stack to a value that can be calculated from the difference in flue gas temperature at constant water content. Referring to the example in figure number 3 which shows the losses when bark at 60% moisture is burned, 13-16% more energy can be produced from the same amount of bark if the amount of flue gas is the same and the gas temperature is decreased from 460°F to 215°F. The utilization of this heat or the purpose of drying will also give the possibility of running the plant at less excess air which in its turn will also decrease the loss.

FURNACE CAPACITY

Before the combustion occurs in the furnace, the fuel must be dried to 10% moisture. This means that at 60% moisture, 1.4 ton of water for each ton of bone dry fuel has to be evaporated before the combustion starts. The heat needed for the drying is taken from the furnace room resulting in decreasing furnace temperature at increasing moisture in the fuel as shown in figure number 4. The evaporation velocity depends on the furnace temperature resulting in a decreasing evaporation capacity at increasing moisture in the fuel and consequently the furnace capacity greatly depends upon the moisture content.

Calculations based on the dependence of the furnace capacity on fuel moisture is graphically shown in figure number 5. The importance is increasing in the area over 40% moisture and decreasing in the other direction which means that in practice there is no advantage in decreasing the moisture under 40% as far as furnace capacity is concerned.

INTERGRATED PRE-DRYING

The utilization of flue gas from the boiler for predrying is operating successfully in two (2) Swedish sawmills, and a flow sheet of such a system is shown in figure number 6. The entire flue gas from the boiler passes through the drier before the final dust collection, and wet bark is transported from the bin into the furnace. As the retention time in the drier is short, about 2 minutes, no extra storage is needed between the drier and the furnace. This gives another benefit. The amount of heat available for pre-drying is proportional to the combusted bark which, because of the short retention time is the same amount as is fed into the drier. In other words, the available heat is proportional to the supplied bark.

The drier researched by our company is a type of cascade drier which offers a specific advantage. There are no moving parts brought in contact with the bark and the contact between bark and construction material is minimized.

Before entering the drier, the flue gas is divided into two streams (figure 7:2), one, the main part passes through a chamber (7:3) before entering the drying chamber (7:1) through circular slots (7:4) the other, and minor part, entering the dryer through a tube ending up in the bottom of the drying chamber (7:7). The gas from the slots flows into the central parts of the drying chamber and forms together with the gas from the central hole a vertical gas stream deflected by a reflector in the upper part of the drier (7:8). By ejection, gas in the periphery flows down into the bottom of the chamber (7:5) where it is mixed with hot flue gases. However, one part corresponding to the fresh gas leaves the drier by the outlet situated above the reflector (7:9). The bark is transported by the gas from the periphery into the central vertical gas stream, where a continuous cascade is formed---broken by the reflector as the bark flows down the periphery into the bottom of the drying changer. In the bottom cone, the outlet slot area which stands in a certain relation to the total cone area is situated (7:11). The amount of bark hitting this slot will therefore be in relation to the total quantity in the chamber and this relationship can easily be changed by a variation of the size of the outlet area. As a result, the drier may be viewed as self regulated.

As the supply of bark entering the system (through a rotary feeder (7:10) increases, the concentration of material in the gas flow will grow. This will increase the quantity of material that strikes the outlet slots and consequently, the amount of material that is discharged. As a consequence of proportionality between the concentration of the material in the gas, the discharged amount and the outlet slot area, it is possible to change the retention time by a simple valve adjustment (7:12).

The gas leaving the drier contains ash from the boiler mixed with fine particles from the drier. These substances must be collected and separated from each other before they reach the stack. For this purpose a multicyclone unit (which was described in an earlier Tappi paper) is installed. (Figure 8) Briefly, the unit consists of a number of cyclone tubes with axial inlet. A vane ring in the cyclone inlet starts the gas spinning and before leaving the unit the gas has to pass through slots in a center tube. The dust is pneumatically conveyed from the unit by slots in the cyclone bottom located between the two tubes. These slots connect the cyclone units with vertical channels which end in a suction chamber evacuated by two separate secondary circuits each consisting of a cyclone and a fan. See figure 9. By arrangement of the connections of the circuits in the chamber; one in the bottom and one in the side, it is possible to separate the combustible material from the ash. The combustible material, which as a consequence of its weight tends to leave the chamber through the bottom outlet, is returned to the dry bark.

In front of the multicyclone unit, a pre-collection hopper is installed to protect the vane ring from being clogged by bark flakes. The hopper is connected to the secondary circuit that handles combustible material and the separated particles are returned to the bark.

THE KARBENNING AND FORSVIK PLANTS

During 1975 the first intergrated pre-drier was installed at the Swedish sawmill Karbenninge angsag AB. The most important data for the plant is as follows:

Drier Capacity	1.5 ton ds/h
Average moisture before the drier	64%
Average moisture after the drier	56%
Flue gas temperature before the drier	230°C. (446°F.)
Flue gas temperature after the drier	105°C. (221°F.)
Evaporated water	0.76 ton/h

One year of experience shows that even if the bark moisture before the drier is as high as 66% it is possible to run the plant without any additional or supplementary fuel. Before the drier was installed the Karbenning angsag had to add supplementary fuel at an annual value of $75,000.00. The furnace in Karbenning is originally designed to burn 1.75 ton/h (3,850 lb/h) b.d. bark at a flue gas temperature of 240°C (464°F) and 60% moisture. This corresponds to a heat flow of 5.8 Mwh (20 MM BTU/h). Since the drier has been installed, 5.8 Mwh is produced by 1.57 ton of bark.

Substantial data concerning the furnace capacity and bark moisture has been reported 1) 2) 3). To confirm the findings a capacity test of the furnace was completed since the installation of the drier.

During the test the amount of bark entering the furnace was measured by the velocity of a calibrated screw feeder in front of the furnace. Because of the high bark moisture, which made it impossible to burn the bark without passing the drier, no comparative test could be done. The tabulated data shown below only indicates how much bark it could burn in the plant.

However, comparing these data with the design data indicates that the reported relationship between bark moisture and furnace capacity is correct.

Capacity test at Karbenning
<u>furnace and boiler design data</u> (without a drier)

Bark moisture	60%
Flue gas temperature	240°C (464°F)
Bark burning capacity b.d.	1.75 ton/h (3,850 lb/h)

<u>Results from capacity test</u> (with a drier)

Average bark moisture before the drier	65%
Average bark moisture after the drier	55%
Flue gas temperature before the drier	250°C (480°F)
Flue gas temperature after the drier	110°C (230°F)
Amount of bark to the furnace b.d.	2.2 ton/h

Another plant located at Forsvik Skogar AB was brought in operation during this spring, and the important data for this plant is tabulated here:

Drier capacity	2 ton ds/h
Average moisture before the drier	60%
Average moisture after the drier	48%
Flue gas temperature before the drier	240°C (464°F.)
Flue gas temperature after the drier	106°C (223°F.)
Evaporated water	1.05 ton/h

A third plant will start operating at Rottneros AB during this autumn. This plant contains a new trend in bark preparation ... see figure number 10. During the winter the bark tends to freeze resulting in poor efficency at pressing. When this happens, the moisture content in the fuel reaches 70% and combustion without supplementary fuel is impossible. As the flue gas temperature after this boiler is low (180°C; 365°F.) the bark moisture will not reach the critical 60% during this period. Therefore, a channel by-passing the economizer has been installed. This arrangement allows the possibility of increasing the flue gas temperature needed for the drying. The amount of gas by-passing the economizer is regulated by a damper and the plant has optimized steam production from the bark moisture. As the net heat value of the bark is dictated by the flue gas temperature after the drier, increase with 10°C (50°F.), a maximum amount of steam is generated by the available bark.

CORROSION

When leaving the boiler, the flue gas temperature is in the area of 350° to 400°C (662 - 752°F.). The last heat is normally recovered in an air preheater or an economizer. For practical reasons, mainly corrosion at combined fired boiler and feed water temperature, the flue gas temperature cannot be decreased under 160°C (320°F.) Finnish investigations of mixed fuel fired boilers confirms that a certain relationship between oil and bark, all sulphuric acid is neutralized by the alkaline fly ash from the wood waste. This relationship differs because of local conditions such as carry over ash content in the wood waste, etcetera. However, when 16% of the heat is generated from wood waste, no sulphuric acid was produced in any of the four (4) investigated boilers. See figure number 11. Consequently, corrosion takes place when little or no bark is used and the flue gas temperature is low. As an intergrated pre-drier installed after the boiler, decreases the flue gas temperature proportionately to the amount of supplied bark which is the same as combusted bark, there is no risk of corrosion in the system.

AIR PREHEATER - ECONOMIZER - BARK DRIER

An important advantage of an intergrated pre-drier is that it is possible to make more steam out of a given amount of bark than with any other system. Therefore, the effect of bark moisture on the furnace capacity increase if the flue gas temperature before the drier is kept at a temperature which results in a bark moisture after the drier of 30-40%. The flue gas temperature required at a different bark moisture to reach 35% is plotted in figure number 12 at different bark moisture before the drier. No attention has been paid to the heating of the bark which takes place in the drier and all heat transferred is calculated as evaporated water.

When increasing the demand of heat for predrying, the combustion air will have to be heated by steam. However, the decreased moisture content in the fuel in the furnace will decrease the demand of super heated air resulting in that low pressure and medium pressure steam could be used for air heating. This in its turn will increase the steam flow through the turbine and consequently increase the production of electrical energy.

CONCLUSION

By utilizing the flue gas loss for pre-drying of the fuel, 10-20% more energy can be produced out of a constant amount of wood waste. If log yard waste is processed to high grade fuel the production can be increased by another 10-20%. As the moisture content dictates the furnace capacity, the capacity can increase from 15 to 40% when the fuel is predried. Most plants can burn their waste in existing combustion equipment.

Finally, if the boiler is combined with a predrier instead of an air preheater and the air is heated by steam, more electrical energy can be produced at an increased total energy production.

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2) Robert C. Johnson
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3) The Swedish Assoc. of Pulp and Paper Engineers
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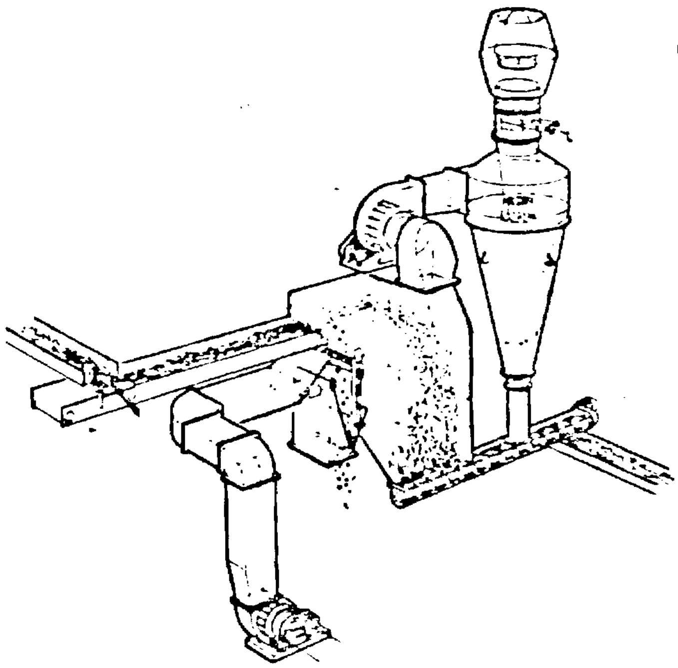

Figure no 1. Bark classifier

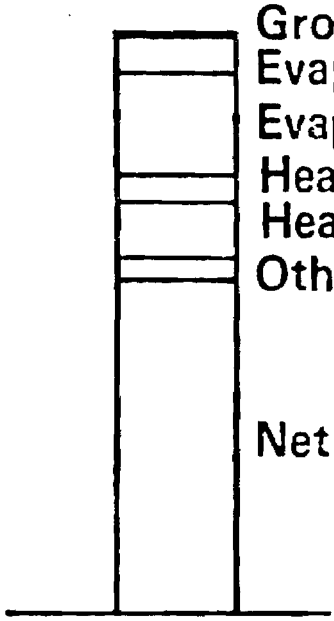

Figure no 2. The net heat value of fuel

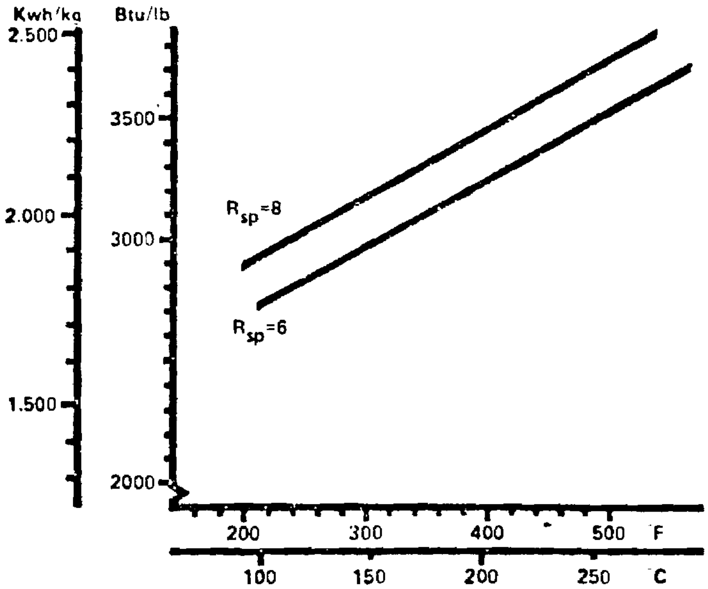

Figure no 3. Flue gas losses from bark burning.
Bark dryness 40%

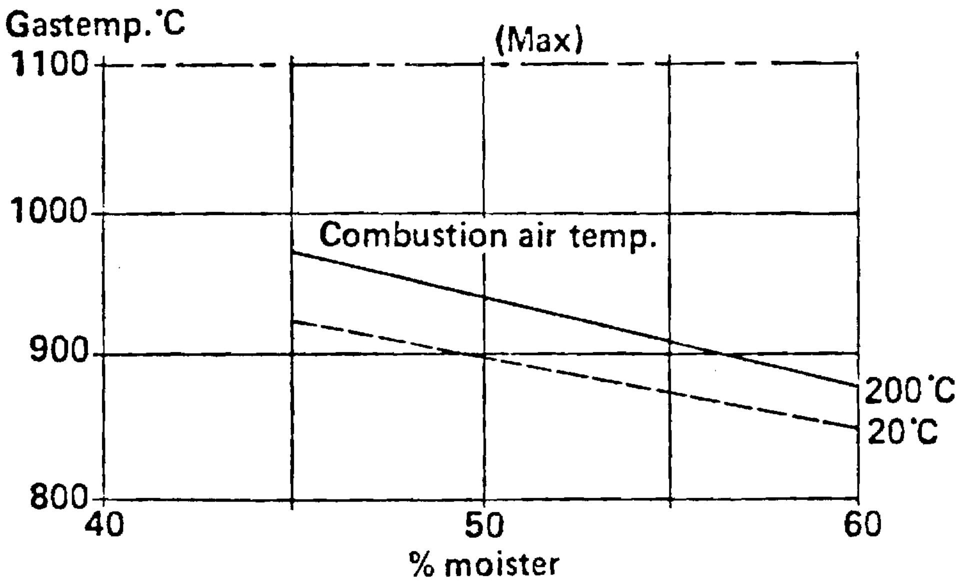

Figure no 4. Gas temprature after slope grate furnance at different bark dryness. Swedish Steam User Ass.

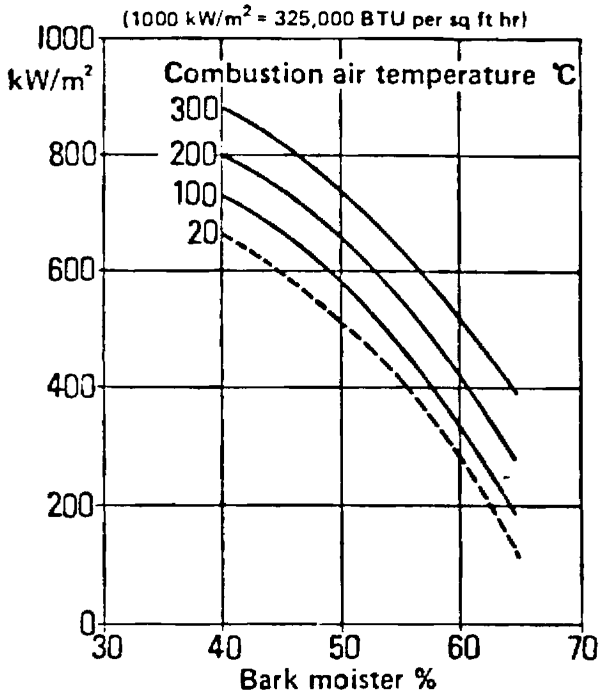

Figure no 5. Slope grate furnace capacity at different bark moister. Swedish Steam Users Ass.

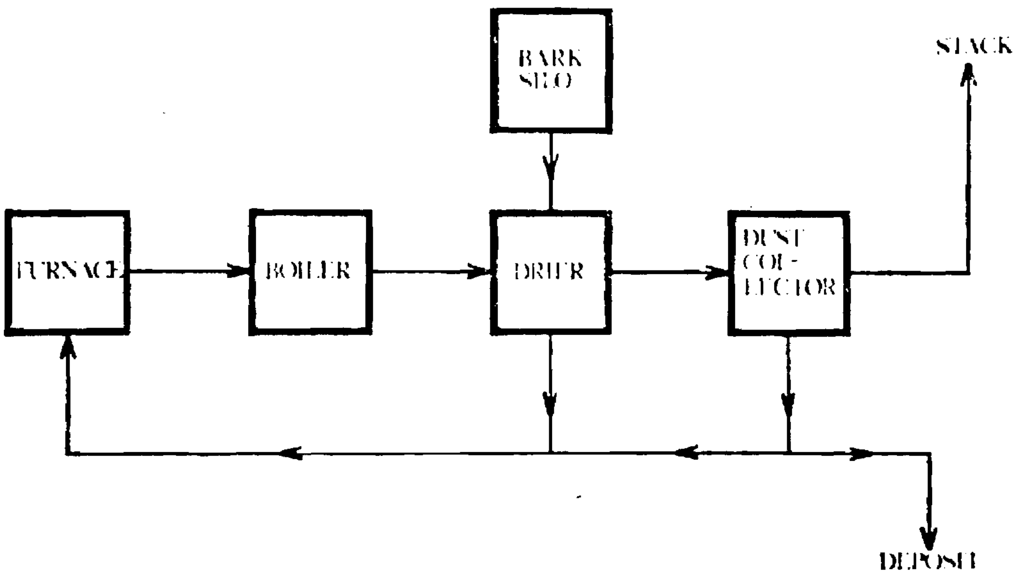

Figure no 6. Intergrated preedrying

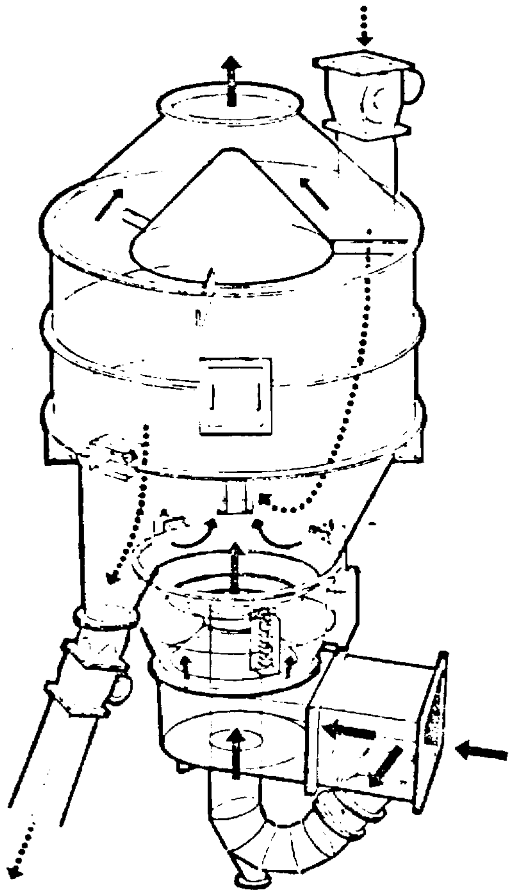

Figure no 7. Cascade drier

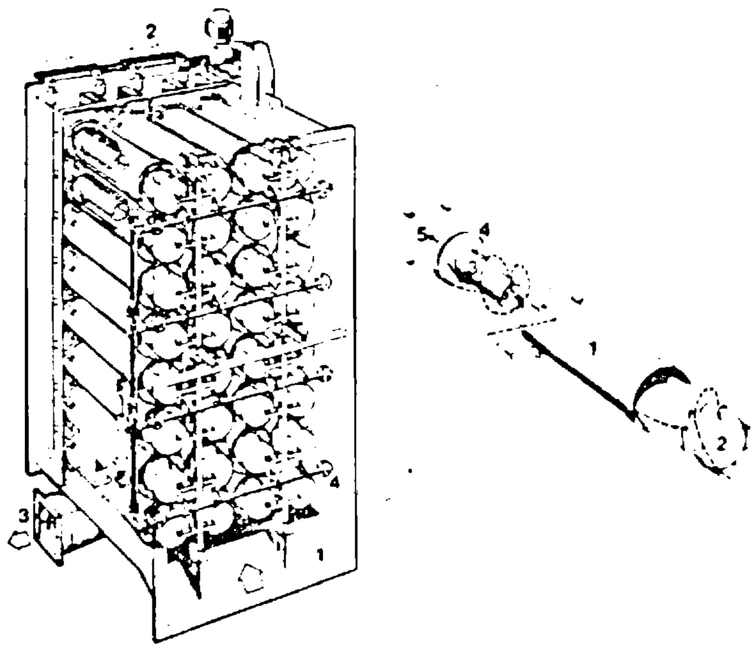

Figure no 8. Multicyclone Unit

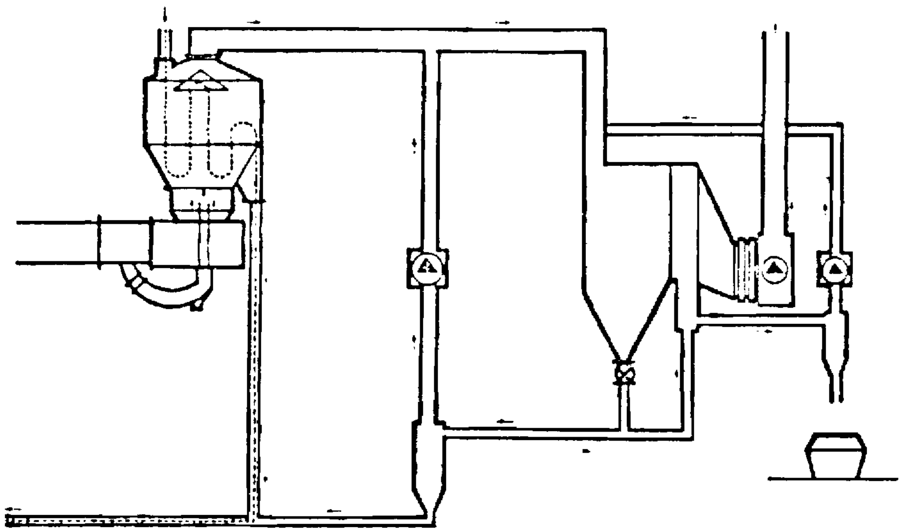

Figure no 9. Flow sheet integrated predrier

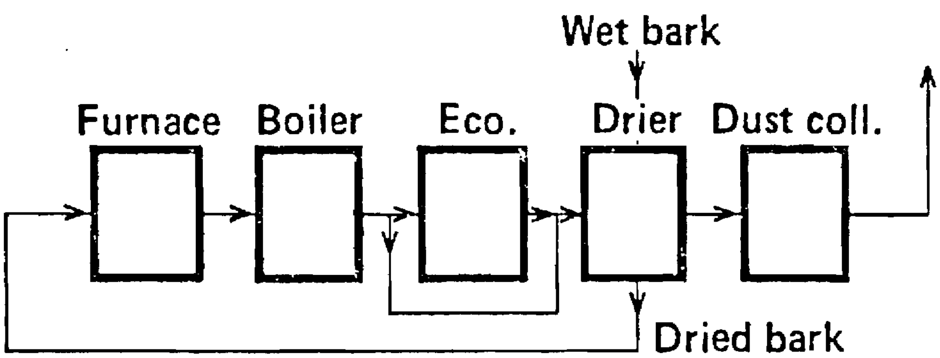

Figure no 10. Flow sheet of the Rottneros plant.

Plant	% steam generated from				
	Oil	Coal	Sulphite waste liqour	Wood waste	SO_3 ppm
A	30	60	0	10	0
A	92			8	5,1
A	100				9,4
B	100				0
B	45			55	0
B	77			23	1,4
C	71		19	10	0
C	100				17,3
C	76			24	0
D	63		37		16,0
D	68		24	8	0

Figure no 11. SO_3 measurements in Finnish industrial steam plants. Econo 116

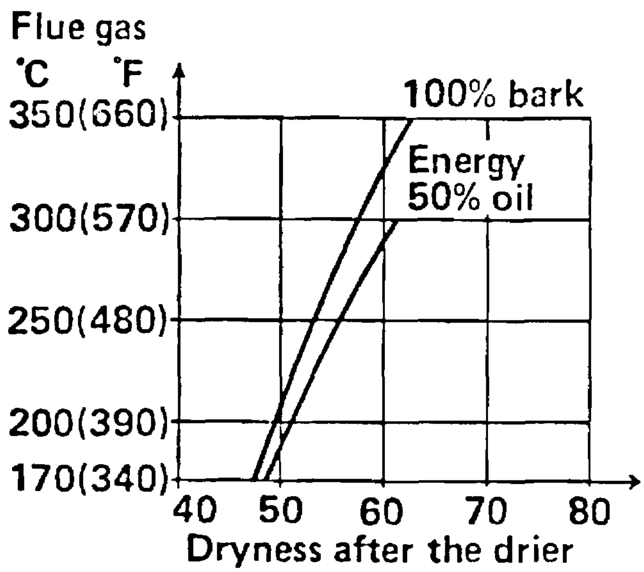

Figure no 12. Bark dryness after the drier at different flue gas temperature. Original dryness 40%. CO_2=14%

Sandwell

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SANDWELL AND COMPANY LIMITED
VANCOUVER B.C. CANADA

COST BENEFIT ANALYSIS OF SYSTEMS

USING FLUE GAS OR STEAM

FOR DRYING OF WOOD WASTE FEEDSTOCKS

Sandwell

Authors: Colin MacCallum
Senior Supervisor Steam and Recovery Department
Sandwell and Company Limited
1550 Alberni Street
Vancouver, British Columbia.
Canada V6G 1A4

Brian R. Blackwell
Process Engineer
Beak Consultants Limited
3051 Shell Road
Richmond, British Columbia.
Canada V6X 2W2

Lars Torsein
Senior Design Engineer, Steam and Recovery Department
Sandwell and Company Limited
1550 Alberni Street
Vancouver, British Columbia.
Canada V6G 1A4

COST BENEFIT ANALYSIS OF SYSTEMS USING FLUE GAS OR STEAM FOR DRYING OF WOODWASTE FEED STOCKS

C. MacCallum, B.R. Blackwell, L. Torsein
Sandwell and Company Limited, Vancouver, B.C., Canada

ABSTRACT

The paper gives brief descriptions and the advantages and disadvantages of several types of hog fuel dryer which employ flue gas, steam or hot air as the heating medium. The environmental aspects and the potential for using flue gas or steam for drying of hog fuel are discussed in the context of both new installations and retrofit applications. Capital costs are developed for several sizes of installation and a cost-benefit analysis is presented.

KEYWORDS

DRYERS: DRYING: HEAT TRANSFER: HOG FUEL: WOOD WASTE: BARK: MOISTURE: COMBUSTION: FLUE GAS: STEAM: COST-BENEFIT ANALYSIS: FEASIBILITY: OPTIMIZATION: EMISSIONS: AIR POLLUTION: BOILERS: CAPACITY: EFFICIENCY: RETROFIT: CAPITAL COST: WASTE HEAT: HEAT RECOVERY: ENERGY: FUEL: SAVINGS.

INTRODUCTION

This paper is a synopsis of a report prepared on behalf of the Canadian Forestry Service, Department of Environment as part of their ENFOR program (1). Much more detail on the systems themselves, the operating problems and the capital costs and financial analyses is contained in the final report which is expected to be published in mid-1981.

Since hog fuel consists of a certain quantity of combustible dry solids and 45-70% moisture by weight (wet basis), there is clearly much to be gained by eliminating as much water as possible prior to the entry of the hog fuel to the furnace of the boiler. The motives for drying are many, valid, and well-documented: As the percentage moisture in the fuel increases, boiler efficiency and evaporation both decrease, and the boiler becomes more difficult to operate: Also as the fuel moisture increases, auxiliary fuel consumption and the power consumption of the boiler ancillaries increase, as does the particulate emission from the unit.

TYPES OF DRYERS

General

Two main categories of dryer were considered:

a. Flue gas in contact with hog
   i. Rotary dryers, Figure 1
   ii. Cascade dryers, Figure 2
   iii. Flash dryers, Figure 3

b. Steam
   i. Indirect, using shell/tube exchanger, Figure 4
   ii. Indirect, using steam/air exchanger, Figure 5

Flue Gas Dryers

Flue gas dryers generally operate under negative pressure: This minimizes dusting problems, but does create other problems such as air infiltration and associated efficiency losses and fire hazards as discussed later.

In the rotary dryer, manufactured by Guaranty Performance, Heil, M.E.C., Rader-Thompson and Stearns-Roger for example, the hog-fuel is repeatedly lifted mechanically by the internals attached to the horizontal rotating shell, or drum, and cascades through, and is carried along by, a flue gas stream passing through the drum.

In the cascade dryer, manufactured by Bahco Systems Inc., the hog fuel enters the dryer, a short vertical cylinder with conical top and bottom, diagonally downwards at one side of the top of the dryer and meets an upward-moving stream of flue gas in the centre of the dryer. A swirling torus of hog fuel and flue gas is developed inside the dryer. The dried fuel leaves the dryer via an adjustable classifier.

The flash dryer, manufactured by Flakt Canada Limited, normally consists of a circular flue or series of flues, normally vertical, through which the hot flue gases carry the hog fuel which is pulverized by a hammermill after a pre-drying section. A classifier ensures that unnecessary grinding does not occur.

The heat in the moisture evaporated from the hog fuel in these flue gas dryers is lost with the flue gases discharging to atmosphere. The flue gases after the dryer, contain combustible fines and also fly ash from the boiler. Since the flue gases are discharged to atmosphere, their particulate and noxious gas emissions are subject to local and Federal regulations. The combustible fines are removed in the dust collection system, either returned to the dried hog fuel system or fed to the boiler directly and burned in suspension.

The methods of emission control are discussed in more detail in the section "Environmental Concerns and Emission Control".

Steam Dryers

In the indirect steam dryer, manufactured by MoDo-Chemetics Ltd., the hog fuel is transported through the tubes of a series of shell-and-tube heat exchangers by a stream of steam, while the heat is supplied to this mixture, by steam at a higher pressure on the shell-side of the heat exchangers. The moisture in the fuel is evaporated at the pressure of the carrier steam and its heat is potentially recoverable in other mill departments which have a use for such steam.

The only dryer of this type has been operating for about 2 years drying pulp, but has operated experimentally for short periods on hog fuel.

In the steam/hot air dryer, manufactured by Mekantransport AB, steam is employed to heat air in a conventional steam-coil airheater, and the air is blown through a slowly moving bed of hog fuel. The heat in the evaporated moisture is not readily recoverable.

As of January 1981, there were 17 cascade dryers (plus 2 on order), 6 rotary dryers, and 1 flash dryer, 1 indirect steam dryer and 1 steam/hot air dryer in operation.

Typically all these dryers would be used to dry hog fuel having an inlet moisture of 65 - 45 percent wet basis, to between 30 and 40 percent for the rotary, cascade and hot air dryers, and to 10 to 15 percent for the flash and indirect steam dryers. The rotary will normally accept material smaller than 75 mm (3 in.) and the cascade will accept 50 mm (2 in.) or smaller. The flash dryer will accept 100 mm (4 in.) or smaller at the predryer inlet, while the indirect steam dryer must be fed with particles smaller than 7 mm (½ in.). The steam/hot air dryer can accept any size which can be handled by the conveying system and the boiler.

ENVIRONMENTAL CONCERNS

General

Environmental concerns related to flue gas dryers involve air emissions whereas the concerns in regard to steam dryers are both air emissions and effluent discharges.

Air Emissions from Flue-Gas Dryers

These are:
- Hydrocarbons
- NO_x
- SO_2 and SO_3
- Particulate.

Hydrocarbon Emissions from Flue-gas Dryers

Hydrocarbon emissions from a flue-gas dryer include both condensable hydrocarbons and hydrocarbon vapours. The condensed hydrocarbons cause a visually-offensive plume, referred to as blue haze. The hydrocarbon vapours which do not condense are an environmental concern because some of them may participate in photochemical reactions in the atmosphere to produce smog.

Hydrocarbon emissions from a flue-gas dryer can be minimized by avoiding excessive temperatures at the particle surfaces. This can be done by avoiding the contact of high-temperature gas with low-moisture particles. Gas recycling of some of the gas leaving the dryer, back to the dryer inlet, avoids particle overheating and thereby should minimize hydrocarbon emissions but, by reducing the temperature-driving-forces for drying, may decrease the rate of drying depending on the temperature and the humidity of the gas entering the dryer.

Hydrocarbon emissions can also be minimized through dryer design. Fine particles, which will dry quickly and rapidly become overheated should have a very short residence time in the dryer, whereas larger particles which dry more slowly should have a longer residence time.

In summary, it is likely that gaseous emissions stemming from the material in the dryer itself can be limited by the use of flue gas temperatures below 315°C (600°F) and by both a uniformity of, and a reduction in, particle size.

Emission of Oxides of Nitrogen

Oxides of nitrogen, NO and NO_2, are environmental concerns for several reasons. Firstly, they are reasonably toxic, particularly NO_2, which, with a Threshold Limit Value of 5 ppm, is about five times more toxic than NO. Secondly, NO_2 enters into photochemical reactions which cause smog, and NO is readily oxidized to NO_2 in the atmosphere. Thirdly, they are absorbed in rainwater, making it more acidic.

Generally the formation of NO increases with increasing combustion temperature (Kester and Pilat; Hood and Miner (5:2)). The higher temperature pertaining when drier fuel is burned will tend to increase the rate of formation of NO but the lower excess air that could be used with the drier fuel would tend to suppress the rate of NO formation.

Hood and Miner (2) measured NO_x emissions from 11 boilers burning wood waste which had average moisture contents ranging from 62 percent to less than 4 percent. Most of the units tested burned fuel containing 45 to 50 percent moisture and only two burned lower moisture content fuel - one 30 percent and the other less than 4 percent. Three-hour-average NO_x emissions ranged from 0.5 to 0.9 g/kg of wet fuel (1 to 1.8 lb/short ton), with no apparent trend of higher NO_x emissions at lower fuel moisture contents. The limit set by the EPA for NO_x emissions from waste wood boilers is 5 g NO_x per kg wet wood (10 lb/short ton). Based on the measurements of Hood and Miner (2), this limit should be met in most cases, regardless of the moisture content of the fuel fired.

Based on the information available, it appears that drying wood waste prior to its combustion does not have a net effect of any significance on NO_x emissions.

Sulphur Dioxide and Sulphur Trioxide Emissions

Sulphur dioxide, SO_2, and sulphur trioxide, SO_3, are an environmental concern because their absorption by rain in the atmosphere results in acidic rain water. Sulphur dioxide and sulphur trioxide emissions result from the incineration of fuels containing sulphur.

Oglesby and Blosser (7) found that only about 5 percent of the 0 to 0.2 percent sulphur in the bark, on a dryweight basis, was emitted as SO_2, with the remainder being accounted for in the alkaline ash combustion products, as sulphates. The reaction of sulphur, oxygen and ash minerals to produce sulphates in the combustion process is responsible for minimizing the conversion of sulphur in woodwaste to SO_2 in the flue-gas.

Oglesby and Blosser (7) did not measure SO_3 but it is likely that its distribution would follow the same pattern as SO_2.

Mineur and Hulden (6) published data on the emission of SO_2 and SO_3 under conditions which involved the simultaneous firing of woodwaste and fossil fuels. Unfortunately, the sulphur contents of the fossil fuels were not specified. Nonetheless, for these situations, when more than about 20 percent of the steam was produced from woodwaste, the SO_3 concentration in flue-gas was less than 1 ppm. The SO_2-concentration in the flue-gas also decreased as the proportion of steam produced from the woodwaste increased. It is probably a reasonable assumption that where a furnace burns only wood waste or woodwaste with a small stabilizing load of fossil fuel, there would be essentially no SO_3 in the flue-gas. This is of special significance and interest when a flue-gas dryer is employed, as the low flue-gas temperatures at the outlet of the dryers cause undue concern about the possibility of corrosion. This aspect is discussed briefly in the section "Operating Problems", later in this paper.

Flue Gas Dryer Particulate Emissions and Control

By drying the woodwaste, there is a significant potential to reduce particulate emissions. This is the case for two reasons. Firstly, drier fuel produces higher combustion temperatures which significantly reduce the discharge of fly ash from the furnace; this was vividly illustrated in R.C. Johnson's (4) experiments on a full-scale boiler. Secondly, with flue-gas dryers, where the flue-gas comes into direct contact with the wood particles, there is the added advantage that the larger particles in the boiler flue-gas are scrubbed out of the gas by impaction on the bark.

The removal of larger particulate by impaction on bark in a rotary flue-gas dryer was apparent in data reported by Sanderson (8).

The specific conclusions that can be drawn from Sanderson's (8) tests for a rotary hog fuel dryer using flue gases are as follows:

1. A considerable proportion, 36 percent, of the salt fume in the flue gases entering the dryer was removed from the flue gas stream and left the dryer with the dry hog fuel. It cannot, however, be deduced that the use of a hog fuel dryer will reduce the emission of salt from a boiler for the same quantity of fuel fired, because, in the tests, the dried fuel plus additional salt was returned to the furnace.

2. The material in the dryer intercepted the bark char from the furnace and replaced it almost entirely with very fine bark particles from the incoming material.

3. A very large proportion (approximately 75 percent) of the inert ash entering the dryer in the flue-gases was intercepted by the dryer, and was returned to the furnace with the dry hog fuel.

4. The dryer reduced the particulate emission from the hog-fuel-fired boiler system by about 45 percent including salt, or by approximately 50 percent on a salt-free basis. Dryer manufacturers also reported reductions in particulate emissions of from 30 to 50 percent on many installations.

5. The "dead load" of material recirculating through the furnace and boiler gas-side passages was increased when a dryer was employed.

6. The particle-size-distribution in the flue gases was dramatically altered. Much finer and lighter particles were emitted when the dryer was employed and dispersion must be substantially better.

Test data are not available from cascade dryers but it is likely that observations very similar to those above would apply.

Increased "dead load" of ash noted in 5. above, caused by recycle of flyash via deposition on the bark in a flue-gas dryer, could increase furnace slagging problems. These problems could be further aggravated by the higher furnace temperatures resulting from the firing of drier hog fuel. Therefore in installations where the ash content of the hog fuel is greater than 5 percent, dry basis, it is recommended that a high-efficiency dust collection system, in the form of specially designed pre-collectors or even an electrostatic precipitator, be used before the dryer in addition to standard large-diameter cyclones or multicyclones after the dryer. This would prevent re-circulation of most of the dust particles back to the boiler with the dry hog fuel, and would reduce ashing and slagging problems, which, as noted in the "Operating Problems" section later in this report, have increased to a certain extent after the introduction of a dryer in some cases. In existing installations, the dryer would best be installed down-stream of the existing dust collection equipment.

Sanderson's (8) test data indicated also that large-diameter cyclone collectors at the outlet of the dryer are adequate to collect the larger fuel particles picked up in the dryer and transported by the gases from the dryer, and will provide a considerably lower total particulate loading in the flue-gases leaving a dryer, compared to that from the dust collection system on the same boiler with no dryer. It should be noted that the particulate loading in the flue gases leaving a cascade dryer is expected to be lower than that leaving a rotary dryer of similar capacity due to the lower exit velocity from the drying zone in a cascade dryer.

Although the total particulate emission from a boiler firing pulverized hog fuel at 10 or 15 percent moisture is expected to be lower than the total particulate emission from a boiler with pile or fluid bed burning, the particulate from the pulverized-fuel-fired boiler is expected to be much finer. For this reason it is anticipated that an electrostatic precipitator will be required to satisfy current emission regulations for new boiler installations, for example, the Level "A" objectives of the B.C. Waste Management Branch for new installations, namely 5.5 mg/mol (0.1 gr/Sdcf).

Plume Visibility

The gas-discharge from a flue-gas dryer is usually at a temperature which is close to the water-vapour dew-point of the gas. This results in a stack plume which is quite dense and highly visible. However, if blue-haze can be avoided by minimizing the volatilization of organics, if smoke can be avoided by using enough excess air, and if the discharge of particulate is controlled, the plume should be white. A white plume, consisting largely of water vapour, would disperse quickly, and, although it would be highly visible, would not be objectionable.

The plume appearance would not be greatly altered by an indirect steam dryer.

Steam Dryer Condensate Discharges and Control

The steam generated by the drying of the bark would contain volatile impurities including terpenes, ethanol, and phenolics, and possibly resin and fatty acids. MoDo-Chemetics indicate the presence of acetic and formic acid as well. MoDo-Chemetics suggests that this steam could be used for presteaming chips, for preheating and concentrating black liquor, for steam mixers, for preheating of air for combustion, for preheating of air for pre-drying of hog fuel or for fresh steam generation. Except for possibly chip pre-steaming, all other uses would usually result in the volatile impurities being discharged to the sewer.

Since the condensate would likely contain some fatty acids and resin acids in most cases, it would probably be quite toxic. Therefore, where the mill had a biological waste treatment system, the condensate produced from the steam from the bark dryer should be routed through the treatment system to reduce its BOD_7 concentration and its toxicity. The aeration capacity of the treatment system would have to be increased by about 35 kW, with an annual operating cost of about $6000, based on 2¢/kWh for a bark dryer evaporating about 8 kg/s (64,000 lb/h) from the hog fuel.

OPERATING PROBLEMS

General

Operating problems discussed in the main report include:

- Availability, defined, in the case of a dryer, as the ratio of the time during which hog fuel is dried, to the time during which hog fuel is available to be dried (96.5% for a cascade dryer according to a test by a user during the first six months of operation).

- Slagging. Slagging increased in two units where the dried fuel was fired in cyclone furnaces originally designed for very wet bark.

- Sootblowing requirements. No significant difference was observed when a dryer was employed. On the flash dryer installation the sootblowers in the superheater and boiler generating bank only required to operate twice weekly since the heating surfaces were very easy to keep clean and no deposits occurred. The economizer was cleaned using a sonic blower and the original shot-cleaning installation was no longer in operation (Westerberg (10)).

- Dusting. Dusting is an engineering design problem requiring a minim... of transfer points, enclosed conveyors, etc.

- Fires, plugging, corrosion, leakage, wear are discussed below in more detail.

Corrosion in Conveyor Systems

Corrosion in the conveyor system from the outlet of the dryer to the boiler can either by efficient venting of the conveyor system at some point perhaps by t scavenging fan, or by the insulation of the entire conveyor, or at least of the the system outside the boiler house. Proper insulation is the preferred solution.

Fires

Of all the installations and manufacturers contacted, there was only one case where minor fires were reported, and these occurred under certain circumstances: The boil... was a... old unit and the setting was reported to be in poor condition: Consequently the unit operated with a very low CO_2, particularly when the ash doors in the furnace w... No other units reported fires in the flue-gas dryer itself. It was noted that ... occurred in the rotary dryer at Canadian White Pine when the unit operated as ... fired dryer: After its conversion to a dryer using boiler-flue-gas, no fires have o...

Directly-fired dryers tend to operate at very much higher temperatures - perh... the range 600-900°C (1100-1650°F), whereas the common factor in all the flue-gas ...ers is that they operate at inlet gas temperatures not exceeding 315°C (600°F).

Several significant factors give extremely low risk of fires in flue-gas dryers:

- The inlet gas temp is less than 315°C (600°F). Rader-Thompson rep... extensive testing had failed to initiate fires at a dryer inlet gas temper... to 315°C (600°F) when wood wafers 12 mm wide, 25 mm long (1/2 in. wide, ... long) were dried.

- Larger particles are close to the dew-point temperature

- Small particles have a short residence time

- The atmosphere in the dryer is oxygen-deficient.

On flash dryer and indirect steam dryer installations, the fire risk in the dry fuel system is clearly higher than in the other dryer installations, because of the extremely low moisture content and finely-divided condition of the dried fuel. In addition, the pulverized fuel, as a fuel-rich mixture, is blown to the boiler using primary combustion air at perhaps 6 kPa (24 in.wg). All fuel lines must obviously be completely sealed, and if short-term storage of the pulverized fuel is required, an inert gas blanket should be employed.

Fires did actually occur in the intermediate storage silo for the dry pulverized ma... the flash dryer installation at Lövholmen in Sweden, during the first six m... operation due to incorrect design of the silo: The material, under certain c... conditions, could bridge over the out-feed screws, and could also hang up in locations in the silo. The original silo was completely replaced and the pulveri... system has been redesigned with a recirculation system and since then neither ... nor fires have occurred (Westerberg (10)).

Although the fire risk in the fuel system of a pulverized fuel unit is higher than in the grate-fired units featuring pile burning on a grate, the risk of fires in the flue-gas train is lower with the pulverized fuel system since there is virtually no carry-over of combustible material from the high-temperature high-efficiency combustion in the furnace. The fly-ash is grey-white and free from carbon in the Lövholmen installation (Westerberg (10)).

Precautions against fires include conventional water-spray systems, steam-smothering systems and, halon gas fire-protection devices.

Plugging

Plugging did not appear to be a problem in the single-pass rotary dryers even when oversize material was introduced, but may be a concern in a multi-pass rotary dryer under such circumstances. One observation was that if the dryer stops rotating for any reason, and the material drops to the bottom of the drum, it is essential that the drive is sufficiently powerful to restart the dryer. In the cascade dryer, the wood waste cascade is maintained by the gas flow through the dryer. If the gas flow from the boiler is reduced for any reason, then the necessary additional gas to maintain the cascade in operation is obtained by recycling gas from the dryer outlet.

The annular gas inlets to the cascade dryer are specially dimensioned to facilitate the clearing of the unit and it was interesting to observe at one cascade dryer visited in the course of this study, that the bark cascade collapsed, and the material fell to the bottom of the dryer: The flue gas temperature leaving the dryer climbed rapidly from 105°C to 150°C (220°F to 300°F) and stayed constant for the few minutes required by the operator to clear the stoppage.

Corrosion

The minimal SO_2 and SO_3-content of the flue gas and the resulting low dew-point result in a low corrosion risk in flue gas dryers.

Active design measures against corrosion include:

- Maintaining minimum outlet temperature of 90-105°C (195-220°F) (controlled by the in-feed of wet material)

- Insulation of downstream surfaces (flues, dust collectors, conveyors)

- Elimination of leaks in casings.

Air Infiltration

The inlet and outlet feeders for the wood waste require special consideration on all flue-gas dryers. Air infiltration in the cascade dryer is not a problem since the casing is fully-welded throughout, but the circumferential seals at the ends of rotary dryers are obvious sites for infiltration, particularly when the seal deteriorates. Air infiltration is reported to be 5 percent at 250-500 Pa (1-2 in. wg) negative pressure on rotary dryers.

Wear

The flights of rotary dryers are subject to abrasion from the tumbling hog fuel, and the seals are subject to wear in normal operation. On three of the larger cascade dryers, wear was noted on the lower slope of the dryer just below the fuel inlet. A fuel slide has been installed from the fuel inlet into the upward gas stream in these dryers with apparent success, and this slide will also be installed on two large dryers now on order for a B.C. coastal installation.

Indirect-steam Dryer Installations - Operating Problems

In view of the lack of operating experience as a hog fuel dryer, of the indirect-steam dryer which was visited , any discussion of the operating problems specific to the dryer itself, must clearly be speculative: The problems related to the dried fuel transportation and firing system have already been discussed above.

Boiler Gross Efficiency and Fuel Quantity

The block diagrams in Figures 6, 7 and 8 best illustrate the reasoning behind the efficiency calculations.

Considering the flue-gas dryers: Where hog fuel at 55 percent moisture is fed to the dryers, the overall gain in the thermal efficiency of the boiler-dryer complex is a result of the lower flue gas temperature, 105°C (220°F), discharged to atmosphere, and the reduction in the excess air required for combustion. As noted earlier, air infiltration occurs at the seals of the rotary dryer, whereas both the cascade and flash dryers are fully-welded and integral with the flues, and there is no additional infiltration.

Regarding the indirect-steam dryer, since the moisture evaporated from the hog fuel is discharged from the dryer at about 400 kPag (60 psig), it can be employed as process steam. The heat in the steam leaving the dryer is at a lower energy level than the steam entering the dryer, but, except for the radiation losses in the dryer and pulverized fuel piping, there is no loss in the total enthalpy of the steam. The pulverized fuel at 10-15 percent moisture is fired in the boiler and there is a substantial increase in boiler gross efficiency.

It can be deduced from the appropriate diagram in Figure 8 that the indirect steam/hot air dryer and boiler are together effectively the same as a boiler with no dryer: The point to note is that since "waste process heat" which the dryer is said to employ as a heating medium could often otherwise be recovered in the feedwater heating train, the heat for the dryer must generally be generated in the boiler in addition to the other process requirements. The boiler evaporation must therefore include the steam used in the dryer heat exchanger.

BOILER PLUS DRYER EFFICIENCY

The flue gas exit temperature conditions and the related overall efficiencies based on the gross calorific value (GCV) of the fuel, at the moisture content which applies for each case are presented in Table I and are shown graphically in Figure 9.

Table I - Assessment of Boiler Gross Efficiency Increase
With and Without Various Types of Dryers

Item	Units	Amount						
Alternative		2n	2nrft	2dr	2dc	2df	2dis	2dha
Boiler		New	Exist. before Retrofit	New, or Existing after Retrofit				
Dryer type		None	None	Rotary	Cascade	Flash	Indirect Steam	Indirect Steam/ Hot Air
Boiler heat output	MW	130	130	130	130	130	130	130
	MBtu/h	440	440	440	440	440	440	440
Gas temperature								
- After last heating surface	^oC	160	220	300	300	355	160	160
	^oF	320	430	570	570	670	320	320
- After dryer	^oC	-	-	105	105	105	-	-
	^oF	-	-	220	220	220	-	-
Fuel moisture content								
- To furnace	% wt	55	55	40	36	15	15	40
- To dryer	% wt	-	-	55	55	55	55	55
Excess air								
- After last heating surface	% wt	40	40	30	30	20	20	30
- After dryer	% wt	-	-	35	30	20	-	-
Efficiency, assessed, gross on fuel GCV	%	65.2	61.5	69.5	69.7	70.2	82.0	74.5

As can be seen from Table I, the increase in efficiency attainable when the moisture content of the fuel is reduced from 55% to say 40% in a rotary or cascade drier is not too significant when compared with the efficiency of a new hog fuel fired boiler with a low flue gas exit temperature. The furnace cross-sectional heat release rate cannot be significantly increased for any small decrease in the moisture content of the fuel, but Figure 10 illustrates the dramatic increase in steam production which can be expected when pulverized fuel firing is adopted at about 15 percent moisture in the fuel. It is therefore the combination of the increase in efficiency and in the furnace cross-sectional heat release rate, which makes retrofit dryers more attractive than dryers on a new boiler-plus-dryer installation.

CAPITAL COST ESTIMATES

Proposed Equipment - New Boiler and New Dryers

The capital and operating cost estimates in the report were developed for hog-fuel-fired boilers having gas or oil as auxiliary fuel, with heat outputs of 130, 65, 40, and 15 MW (that is 440, 220, 140, and 50 MBtu/h) equivalent to steam capacities on hog fuel alone of 50, 25, 15, and 6.5 kg/s (400, 200, 120, and 50 klb/h).

The gas temperature at the outlet of the last heating surface of the boiler, on hog fuel alone, was assumed to be 160°C (320°F) without a dryer, and 300°C (570°F) with a dryer.

The gross calorific value of the bone dry hog fuel was assumed to be 20.2 MJ/kg (8 700 Btu/lb) and the moisture content at the inlet of all the dryers was assumed to be 55 percent by weight.

On any dryer application, the arrangement of the conveyors, and or steam lines, would be designed specifically for each site, so for the purposes of this study, estimates of a general nature are required, and a number of basic assumptions, outlined below, have been made:

The following structures, including appropriate foundations, have been assumed for the various types of dryers:

a. Rotary Dryer Structures
Only the dryer and the drive, and operating floor are enclosed; the cyclones and the booster fan are outdoors.

b. Cascade Dryer Structures
Outdoor installation including several floor grating levels.

c. Flash Dryer Structures
Partially enclosed installation; only the wind classifiers and pulverizers would be enclosed.

d. Indirect Steam Dryer Structures
Essentially an outdoor installation with access galleries; only the pulverizer would be enclosed.

e. Indirect Steam/Hot Air Dryer Structures
Only the airheater and forced draft fan would be enclosed.

It has been assumed that two stages of high-efficiency multicyclone collectors, with shaveoff would be adequate to achieve, for example, the Level "A" objectives of the B.C. Waste Management Branch on a boiler with a well-defined primary combustion zone and moderate grate-heat-release rate, with no dryer.

When the boiler is fitted with a rotary flue-gas dryer, a cascade dryer, or an indirect steam dryer the dust collection equipment included in the costs for the flue-gas dryer is therefore as follows:

- Rotary dryers: Two stages of conventional multicyclone collectors at the inlet of the rotary dryers and large-diameter cyclone collectors at the outlet of the rotary dryers: A separate dryer fan has also been included.

- Cascade dryers: Multicyclone collectors and integral precollector at the outlet of the cascade dryers, together with the associated discharge and return system, to return the unburned fines, carried-over in the flue gas stream from the dryer, to the dried-hog-fuel conveyor to the boiler.

  It has also been assumed that the ash content of the hog fuel is less than 5 percent by weight, dry basis, so no precollector has been included upstream of the cascade dryer.

- Flash Dryers and Indirect-steam Dryers: For the boiler firing pulverized hog fuel at a moisture content of 10-15 percent, wet basis, a two-chamber electrostatic precipitator and ancillaries has been included after the last heating surface of the boiler and upstream of the induced draught fan.

Proposed Equipment - Dryer Retrofit - Existing Boiler/New Dryers

In order to reduce the number of dryer options obtained from the manufacturers, for the purposes of the capital cost estimates in this study, the retrofit dryers were assumed to have the same hog fuel drying capacities as the dryers in the new boiler and dryer installations described in the previous section, and the same proposals were used as the basis of the capital costs.

Dryers which deliver fuel at 30 percent moisture content and above can be retrofitted on all types of hog-fuel-fired boilers where some type of grate is employed; dryers which dry the fuel to lower moisture contents — say 10 to 15 percent — would be expected to employ pulverized hog fuel firing through burners in the furnace walls.

On any retrofit dryer application, even more so than on the new boiler/dryer installation, the arrangement of the conveyors, and flues or steam lines, would be designed specifically for each site, so for the purposes of this study, estimates of a general nature were required, and a number of basic assumptions in addition to those noted for the new dryer/boiler installation, outlined below, have been made:

- Dust Collection Equipment

  It has been assumed that the emissions from the boiler to be fitted with a retrofit dryer, are already in compliance with the local regulations. If the boiler were not in compliance, as is the case in many instances, then the additional dust collection equipment required to bring the boiler into compliance would be required whether or not a dryer were to be installed, and should be charged to a (separate) emission control project, and not to the dryer project.

It has again been assumed that the ash content of the hog fuel is less than 5 percent by weight, dry basis, so no precollector has been included upstream of the dryer. The only dust collection equipment included in the costs for the retrofit flue-gas dryer are therefore large-diameter cyclone collectors at the outlets of the rotary and cascade dryers, together with the associated discharge and return system, to return the unburned fines, carried-over in the flue gas stream from the dryer, to the dried-hog-fuel conveyor to the boiler.

For the boiler firing pulverized hog fuel at a moisture content of 10-15 percent, wet basis, a two-chamber electrostatic precipitator and ancillaries has again been included after the last heating surface of the boiler and upstream of the induced draught fan.

- Dryer Fan

A new dryer fan to provide the additional draft required by the rotary, cascade, and flash dryers and dust collectors, has been included in the capital cost estimates.

General

The capital costs in the report take account of the reduction in the size of the new boiler when integrated with a dryer installation, and are presented graphically in Figure 11. Figure 12 illustrates the costs for retrofit dryers.

It can be seen that the costs of the dryers vary quite widely according to the type of dryer.

New boiler and integrated dryer installations are all more expensive than new boilers with no dryers.

The estimates are based upon budget proposals from manufacturers, obtained in December 1980 and January 1981 for major items of equipment, while the remainder of the costs are based on data from Sandwell files.

The estimates were intended to be suitable for the calculation of return on investment and for the purposes of the cost benefit analysis of this study. For a specific installation, similar initial feasibility-grade estimates could be prepared, but in the event that the decision were made to proceed with the project, the estimates would be presented in greater detail in a construction budget for cost control of the project during construction.

The estimates exclude the following items:

1. Federal sales tax.
2. Interest on borrowed capital during construction.
3. Plant pre-operating and start-up expense.
4. Escalation.

The estimates provide for the cost of structures, equipment, and services, and include freight, B.C. Provincial sales tax amounting to 4 percent for all material including equipment, installation labour including the expenses of a general contractor, Owner's construction overhead, engineering cost and a contingency allowance.

OPERATING COST ESTIMATES

General

The operating cost estimates were based on:

- Boiler efficiencies of 85 percent on oil firing and 65 percent on hog fuel firing based on the GCV of the fuel, for the new boiler with no dryer
- Hog fuel cost of 9 \$Can./BDt, an oil cost of 130 \$Can./m^3 (20.7 \$Can./bbl) and a power cost of 0.02 \$Can./kWh
- 8200 operating hours per year.

No additional personnel are expected to be required to operate the dryer.

For boiler operating costs it has been assumed that the boiler operates at its design level as a base-load operated unit. In many mills the boiler might well operate at a somewhat lower load on average, to reflect the fluctuations in process steam demand.

No account has been taken of the relatively small drop in in-house power generation, due to the use of steam at 1200 kPag (170 psig) in the dryer, which would occur at a site with a turbine generator.

Figure 13 shows that the power consumptions of dryers drying fuel to 15 percent moisture are considerably higher than the power consumptions for dryers which yield 40 percent moisture hog fuel at the outlet of the dryer.

Using the above operating cost data it can be shown that the payback times for new boiler and dryer installations are extremely unattractive relative to the cost of a new boiler with no dryer: Payback times ranged from 15-100 years for the rotary dryer, from 17-35 years for the indirect steam dryer, and negative payback times resulted for the flash dryer. This may appear unreasonable, at first sight, but it must be noted that, except under certain circumstances, no significant oil savings can be expected with a new boiler plus dryer, relative to a new modern boiler for the same evaporation. Modern boilers in which a travelling grate is employed in a furnace with a well-defined primary combustion zone are specifically designed for burning hog fuel up to a moisture content of 62 percent (Topley, (9)), and boilers with a bare-tube-panel sloping grate and reciprocating foot grate for continuous ash removal are designed to burn up to 65-70 percent moisture hog fuel (Jägerlund (3)). Extensive tests on these types of boilers, reported by Topley and Jägerlund, indicate that such boilers can follow considerable swings in process steam demand without recourse to oil or natural gas.

Oil savings would, however, be achieved on a new boiler and dryer installation if only a limited quantity of hog fuel were available. Under such circumstances the efficiency gain from the use of the dryers would improve the payback. The high efficiency of the indirect steam dryer would then be of interest, although the lack of operational experience is a disadvantage. Also, if a boiler lacking the load-swing-matching capability were purchased, and if the support oil consumption were equivalent to 5 percent of the boiler heat output with no dryer, then a reduction to perhaps 2 or 3 percent could be expected if a rotary, cascade or steam/hot air dryer were installed. Support oil would theoretically be eliminated in the pulverized firing alternatives associated with the flash and indirect steam dryers but in practice as much as 5 percent may still be used in a pilot role (Westerberg (10)).

Assuming a boiler heat output of 65 MW (220 MBtu/h) from hog fuel at 55 percent moisture, corresponding to a Steam Production Factor of 79 according to Figure 10, prior to the retrofit, the anticipated heat output from dried hog fuel is presented for each type of dryer, in Table II. It has been assumed that the new capacity can be absorbed by the process heat loads, and that the additional generation from hog fuel replaces steam which was previously generated from oil.

Again, no additional personnel are expected to be required to operate the dryer.

Even using the relatively low western Canadian base operating cost data, Table II indicates that retrofit dryers are extremely attractive. The payback times range from 1.4 years with the flash dryer to 3.3 years for the cascade dryer. The payback time for the steam/hot air dryer is always negative as explained above, unless the steam for the dryer can be supplied at no cost. Again, no account has been taken of the relatively small drop in in-house power generation potential due to the use of steam at 1200 kPag (170 psig) in the indirect steam dryer.

On a new boiler/dryer installation, except under certain circumstances, there would be no significant fossil fuel saving as discussed above, but the retrofit dryer reduces fossil fuel consumption in an existing plant where a proportion of the process heat is presently supplied from fossil fuel, or can satisfy a certain increase in steam demand without recourse to additional fossil fuel.

Maximum advantage can be taken of the inherent potential additional evaporative capacity of a grate-fired boiler with no dryer, if at the design stage, provision is made, both in the boiler design and layout, for the future installation of a dryer plant.

<u>Table II - Anticipated Heat Output, Net Annual Operating Costs, and Gross Pay-back Time for Boilers after Installation of Retrofit Dryer</u>

Item Alternative	Units	Amount 2dr	2dc	2df	2dis	2dha
Fuel moisture						
- To furnace	% wt	40	36	15	15	40
- To dryer	% wt	55	55	55	55	55
Steam production factor (Fig. 10)		92	95	200	200	92
Boiler heat output from hog fuel						
- Before retrofit	MW	65	65	65	65	65
	MBtu/h	220	220	220	220	220
- After retrofit	MW	76	78	165	165	76
	MBtu/h	260	266	563	563	260
- Increase after retrofit	MW	11	13	100	100	11
	MBtu/h	40	46	343	343	40
Hog fuel fired						
- Before retrofit	BDT/a	154,450	154,450	154,450	154,450	154,450
	BDST/a	170,290	170,290	170,290	170,290	170,290
- After retrofit[1.]	BDt/a	159,800	163,540	343,490	294,060	149,080
	BDST/a	176,190	180,300	378,700	324,200	164,360
- Increase (decrease) after retrofit	BDt/a	5,350	9,090	189,040	139,610	(5,370)
	BDST/a	5,900	10,010	208,410	153,910	(5,930)
Power consumption (Fig. 14)						
- Increase after retrofit	kW	260	390	1,780	1,910	325
Fossil fuel heat replaced by hog fuel	MW	11	13	100	100	11
	MBtu/h	40	46	343	343	40
Oil replaced by hog fuel						
- Quantity	m^3/a	9,395	11,100	85,400	85,400	9,395
	bbl/a	59,100	69,820	537,200	537,200	59,100

Note: 1. Note efficiency increase - Table I.

Table II - Cont'd

Item Alternative	Units	Amount 2dr	 2dc	 2df	 2dis	 2dha
Steam to dryer						
- Consumption	kg/BDkg	Nil	Nil	Nil	Nil[2.]	1.25
	lb/BDlb					1.25
	t/a					186,350
	ST/a					205,450
Cost savings (Increases)						
- Hog fuel	$Can./a	(48,000)	(82,000)	(1,701,000)	(1,265,000)	48,000
- Oil Cost	$Can./a	1,221,000	1,443,000	11,103,000	11,103,000	1,221,000
- Power Consumption	$Can./a	(43,000)	(64,000)	(292,000)	(313,000)	(53,300)
- Steam	$Can./a	Nil	Nil	Nil[2.]	Nil	(1,600,000)
Net savings after retrofit	$Can./a	1,130,000	1,297,000	9,110,000	9,534,000[3.]	1,216,000[4.] Negative[5.]
Total Capital Cost installed (Fig.12)	$Can.	3,200,000	4,300,000	12,970,000	16,704,000	4,200,000
Gross Pay-back time	years	2.8	3.3	1.4	1.75	3.45[4.]/ /Negative[5.]

Notes: (Cont'd)

2. Assuming that the moisture evaporated from the hog fuel is received.
3. Not account has been taken of the relatively small drop in in-house power generation potential due to the use of steam at 1200 kPag in the incorrect steam dryer.
4. Assuming steam requirements for 2dha at no cost.
5. Assuming steam requirements for 2dha at costs shown in parentheses above.

FINANCIAL EVALUATION

The discounted cash flow internal rates of return were calculated to examine the financial implications of retrofit dryers. The bases for the analyses were, an economic life of 20 years, no salvage value, maintenance cost of 2 percent of the capital cost, and a tax rate of 45 percent. Two Capital cost allowance (depreciation for tax purposes) alternatives were considered, namely, 50 percent straight line depreciation, and 20 percent declining balance.

The after-tax internal rates of return appear to be most attractive for retrofit dryers, and ranged from approximately 25 percent for the rotary, cascade and hot air dryers, to 42 and 50 percent respectively for the indirect steam and flash dryers, based on the 50 percent straight line calculation. The 20 percent declining balance approach yielded rates of return which were 4 to 12 percent lower.

Sensitivity analyses were conducted to estimate the internal rates of return for retrofit dryers, as a function of changes in the key cost factors. The results for the rotary dryer are shown graphically in Figure 14. The analysis for the flash dryer showed a similar configuration except that the initial return on investment was much higher than for the rotary, and also that the return on investment was somewhat more sensitive to increases in the cost of electric power.

CONCLUSIONS

The following general conclusions can be drawn from the study:

1. Flue-gas dryers, (rotary, cascade, flash) are proven technology for hog fuel drying.

2. The indirect steam dryer has potential for drying hog fuel efficiently but more operational experience is required.

3. Operating experience from several installations has demonstrated that the stack particulate emissions are always lower when a flue-gas dryer is in operation than when the same unit is operated with wetter fuel without a dryer.

4. A review of the literature indicates that the drying of wood waste prior to its combustion does not have a significant impact on the NO_x emission from the installation, and that existing NO_x emission limits are not likely to be exceeded when a dryer is installed. The literature also indicates that there should be essentially no SO_3 in the flue gas in a boiler burning only wood waste, or wood waste with a small stabilizing load of fossil fuel. Also, the SO_2-concentration in the flue gas decreases as the proportion of steam generated by the woodwaste increases, so hog fuel drying, by reducing the use of fossil fuel (oil), contributes to reducing corrosion in boiler heating surfaces and associated flue gas systems.

5. Hydrocarbon emissions are minimized by the use of flue gas temperatures below 315^{o}C (600^{o}F) and by the short residence time of the small particles which would otherwise become overheated.

6. The additional power consumption associated with the dryer installation is estimated to be about 1800 kW - that is, less than 2 percent of the anticipated increase in the heat output of the boiler when firing wood waste.

7. On new installations for hog fuel feedstocks having a moisture content of up to approximately 62 percent , depending on the design of the boiler, dryers are unjustified, except where the hog fuel supply is limited.

8. Dryers are most attractive on retrofit applications.

9. The flash dryer appears to be the most attractive type of dryer for retrofits on boilers having heat outputs as low as 60 MW (200 MBtu/h).

10. On new installations, where no dryers are installed initially, provision should be made, both in the boiler design and in the layout, for the future installation of hog fuel drying equipment.

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LIST OF FIGURES

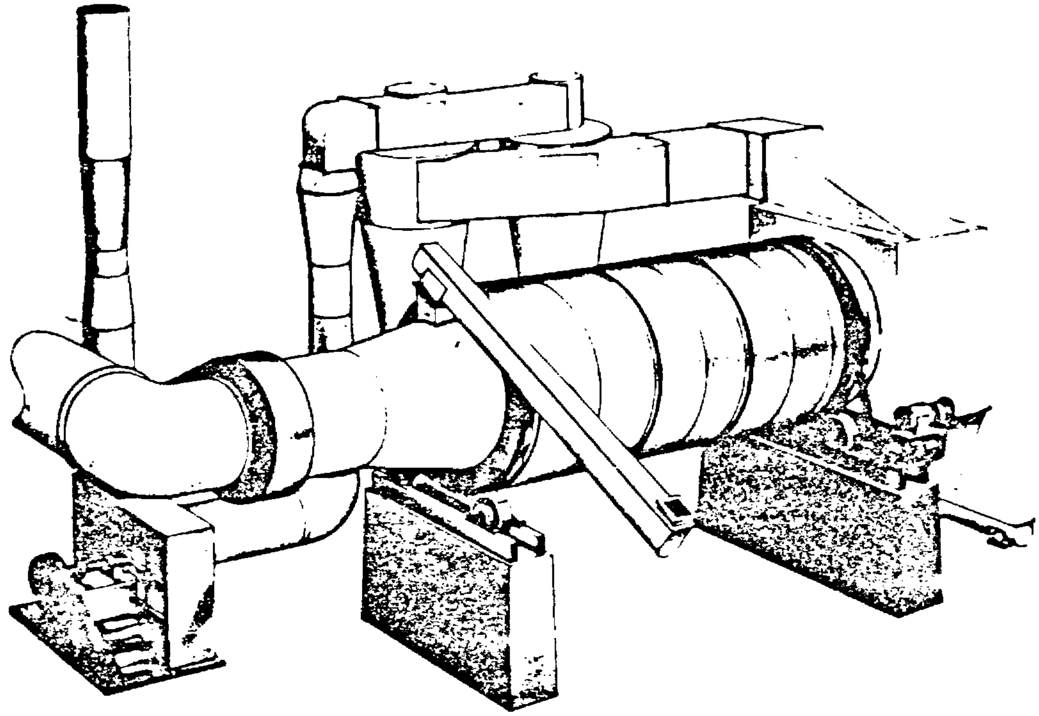

Figure 1 Rotary dryer.

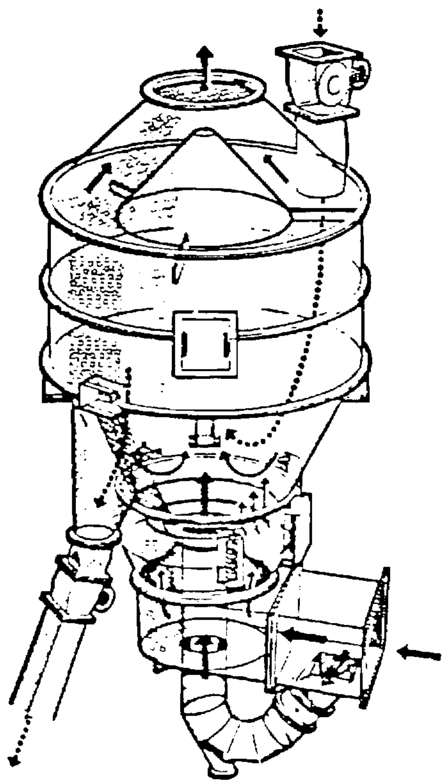

Figure 2 Cascade dryer.

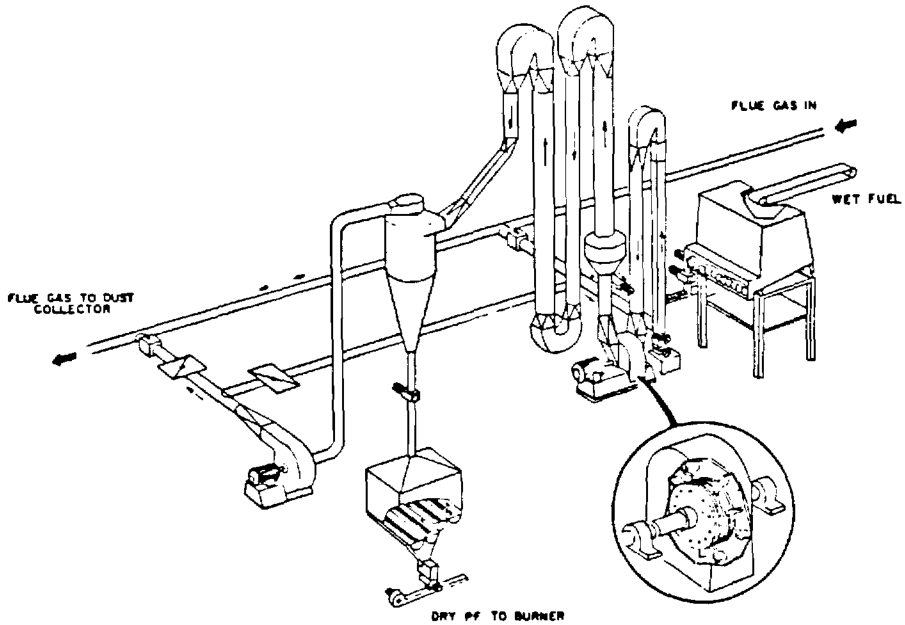

Figure 3 Flash dryer.

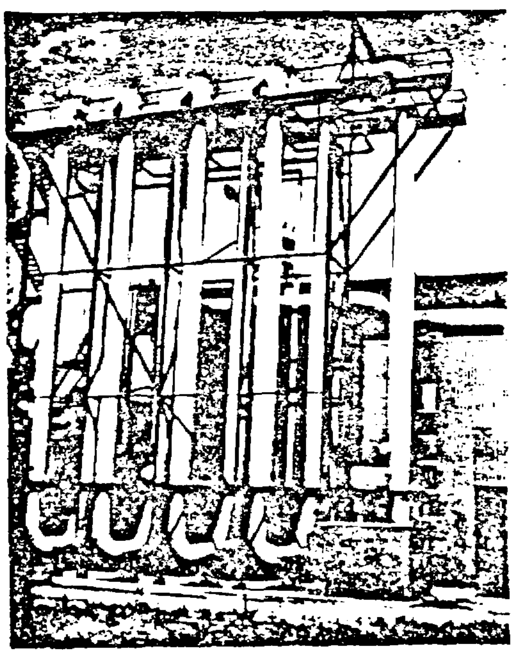

Figure 4 Indirect steam dryer.

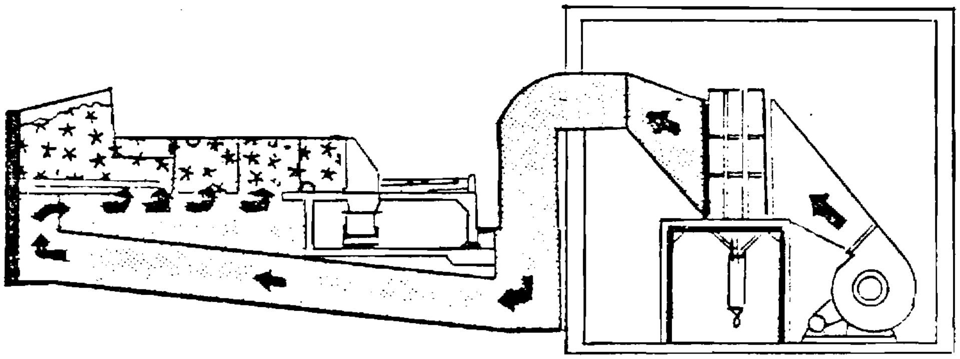

Figure 5   Indirect steam/hot air dryer.

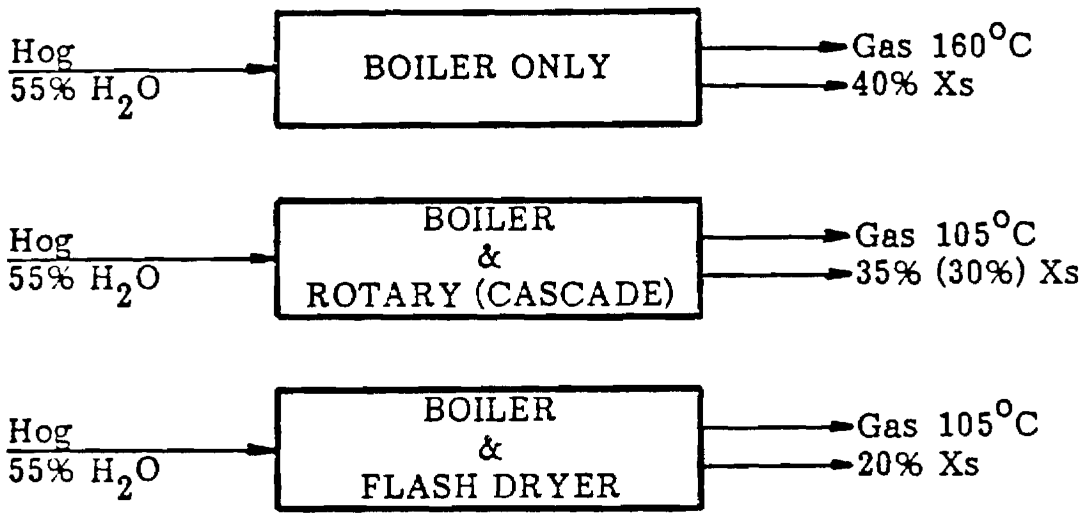

Figure 6 Flue-gas dryers, block diagrams.

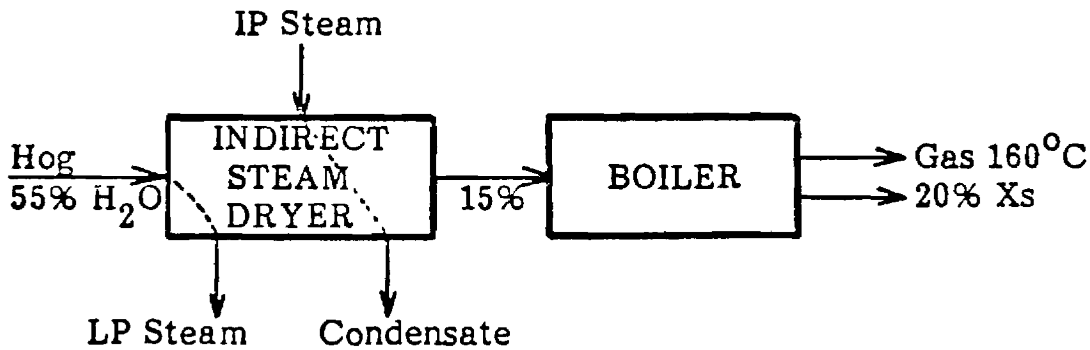

Figure 7 Indirect steam dryer, block diagram.

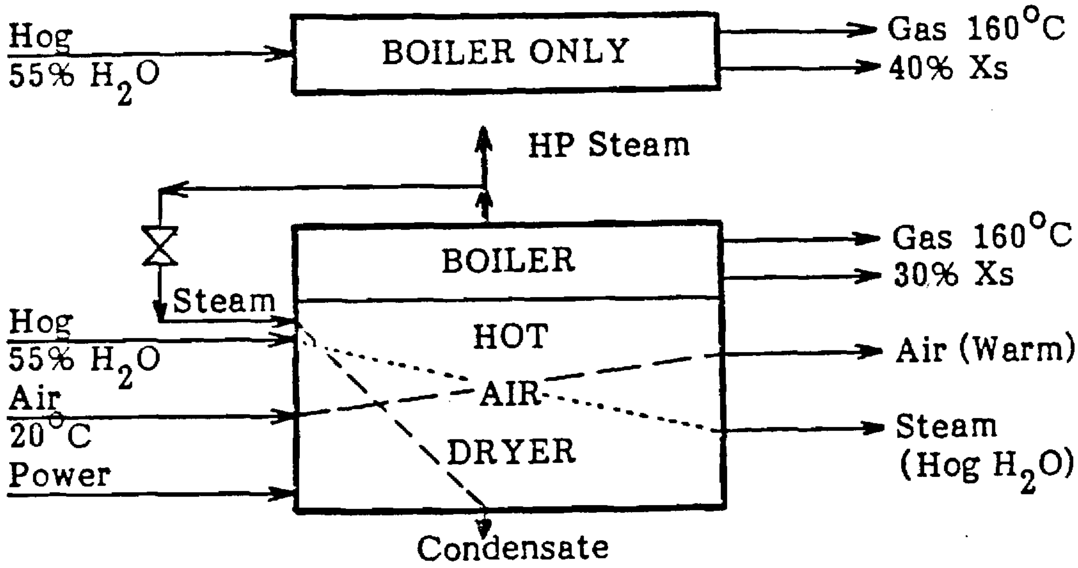

Figure 8 Indirect steam/hot air dryer, block diagram.

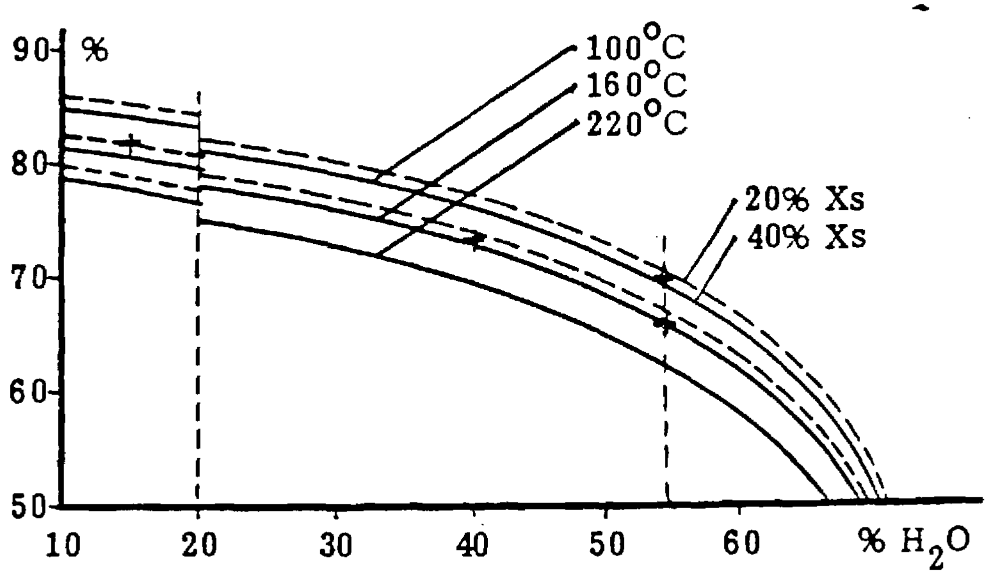

Figure 9 Boiler gross efficiency on the GCV of hog fuel, as a function of hog fuel moisture content.

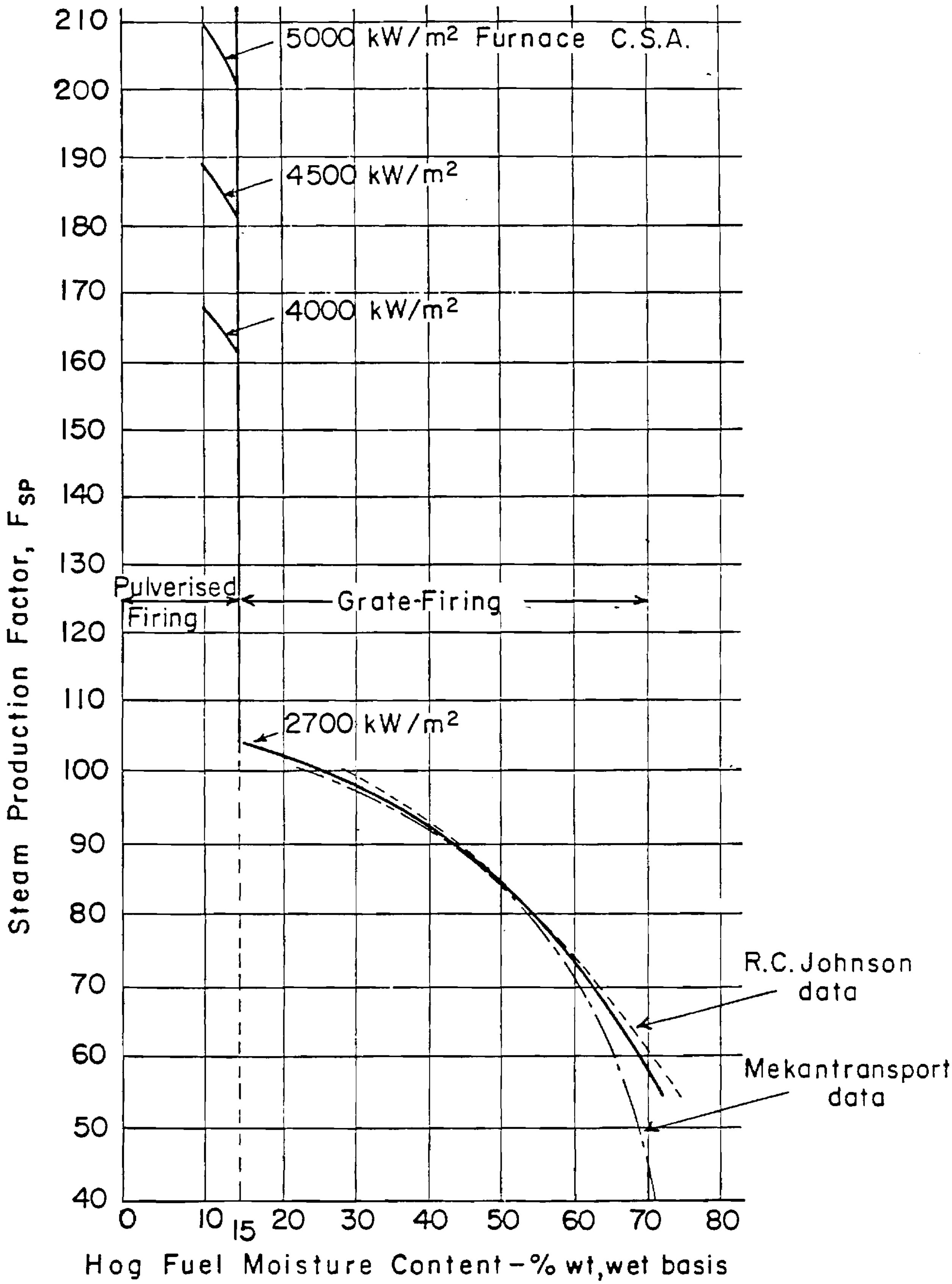

Figure 10 Steam production factor as a function of hog fuel moisture content.

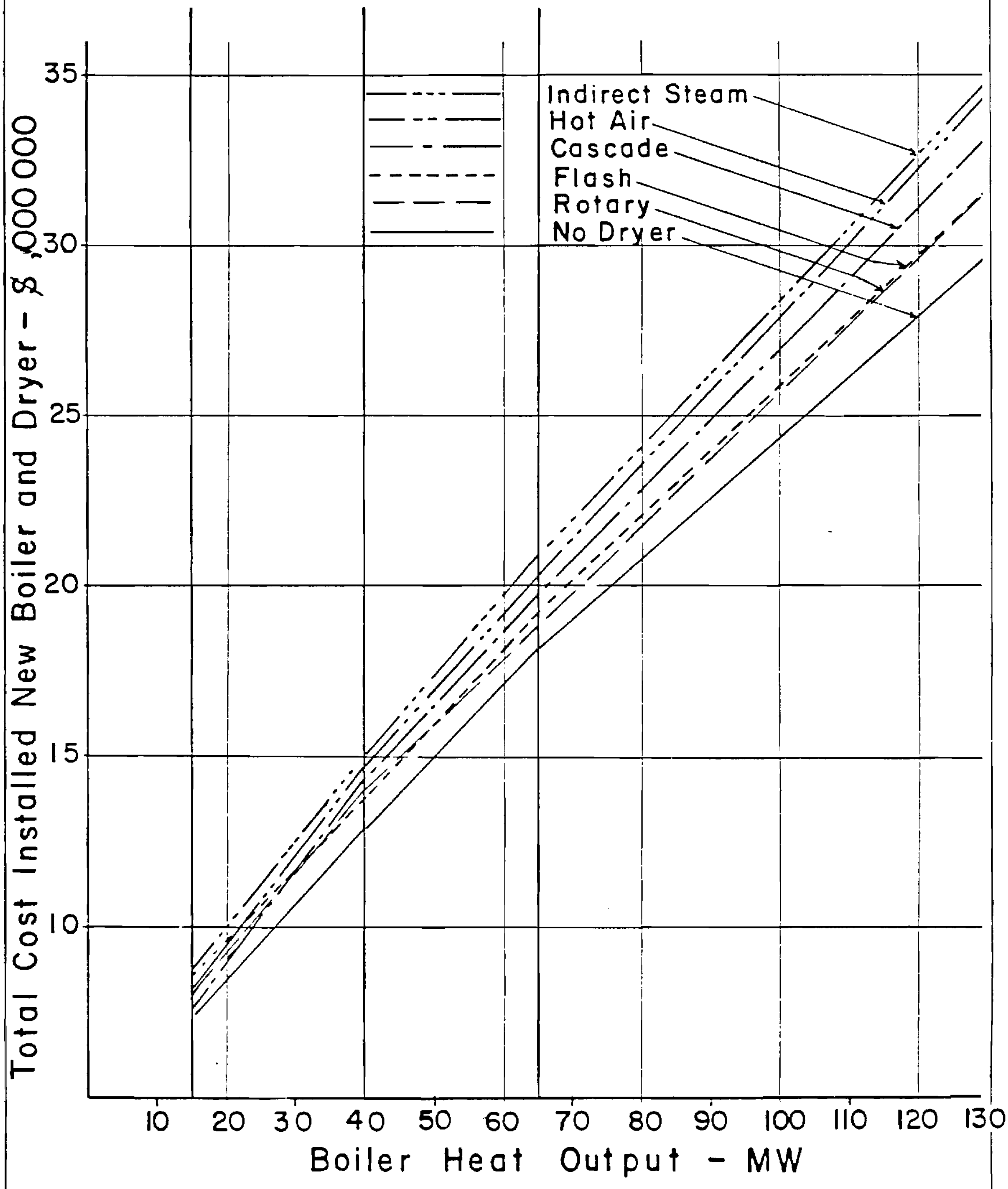

Figure 11 Anticipated total plant cost installed, new boiler and dryer installations.

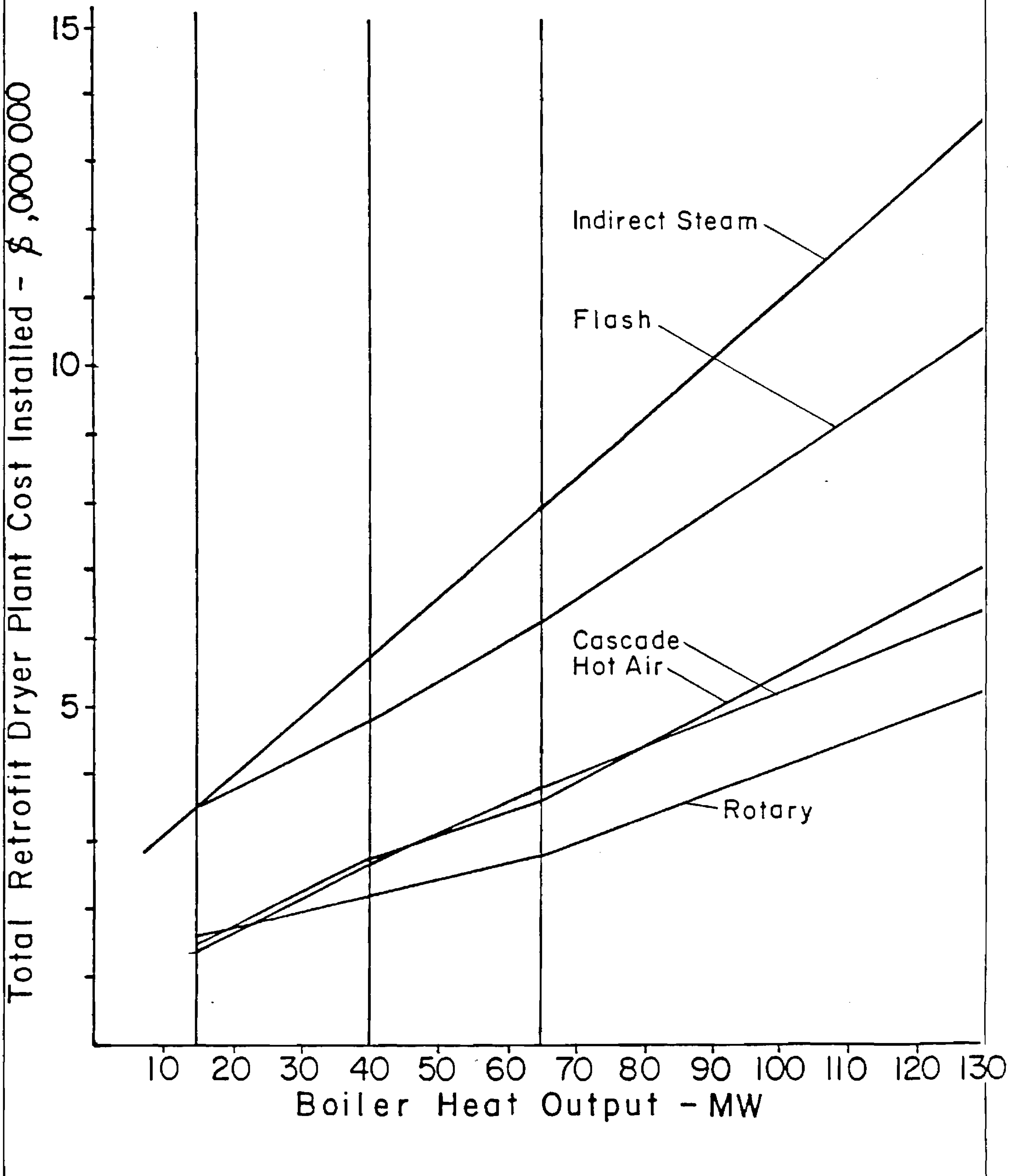

Figure 12 Anticipated total plant cost installed, retrofit dryer installations.

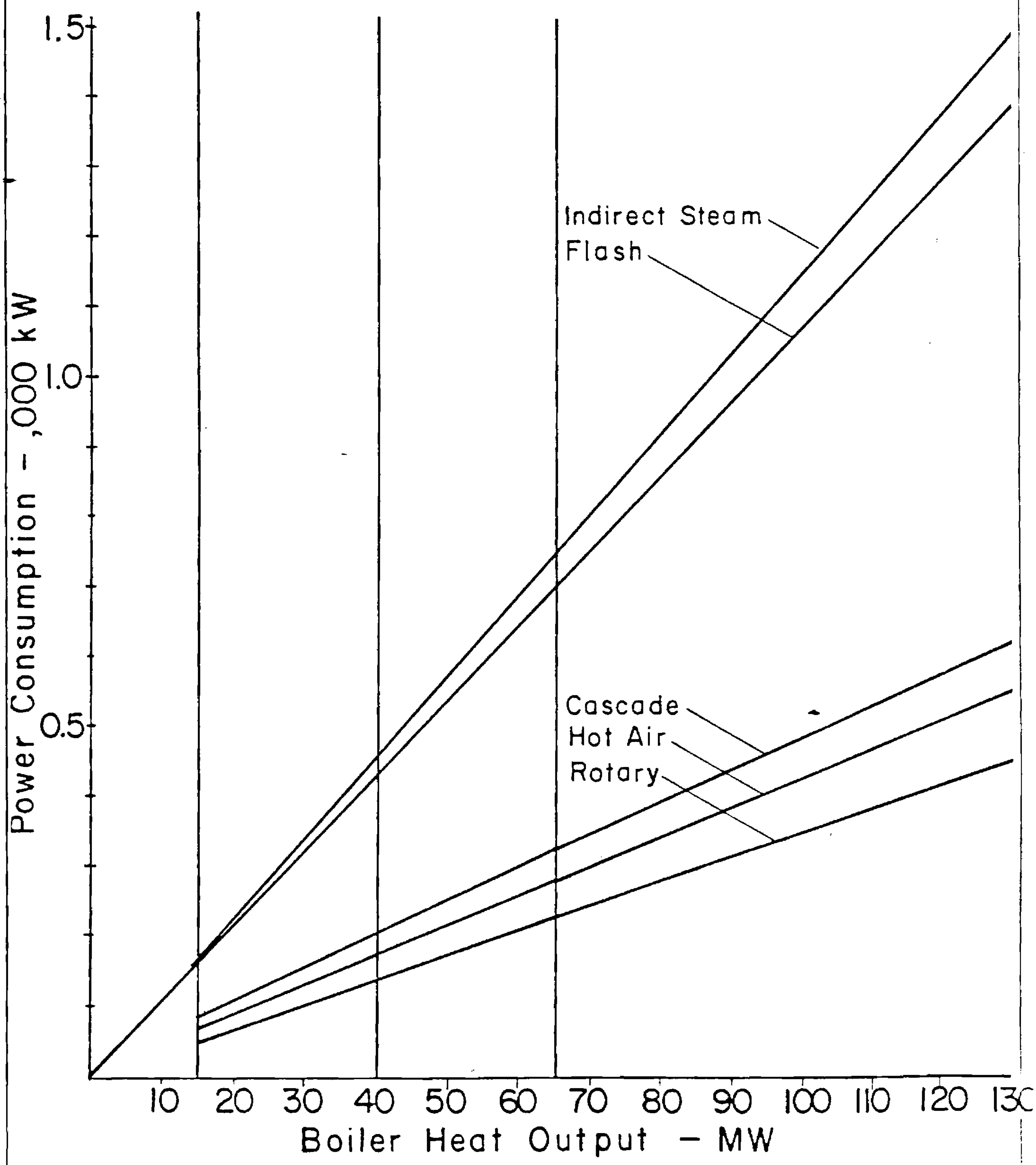

Figure 13 Anticipated additional power consumption of retrofit dryer plant.

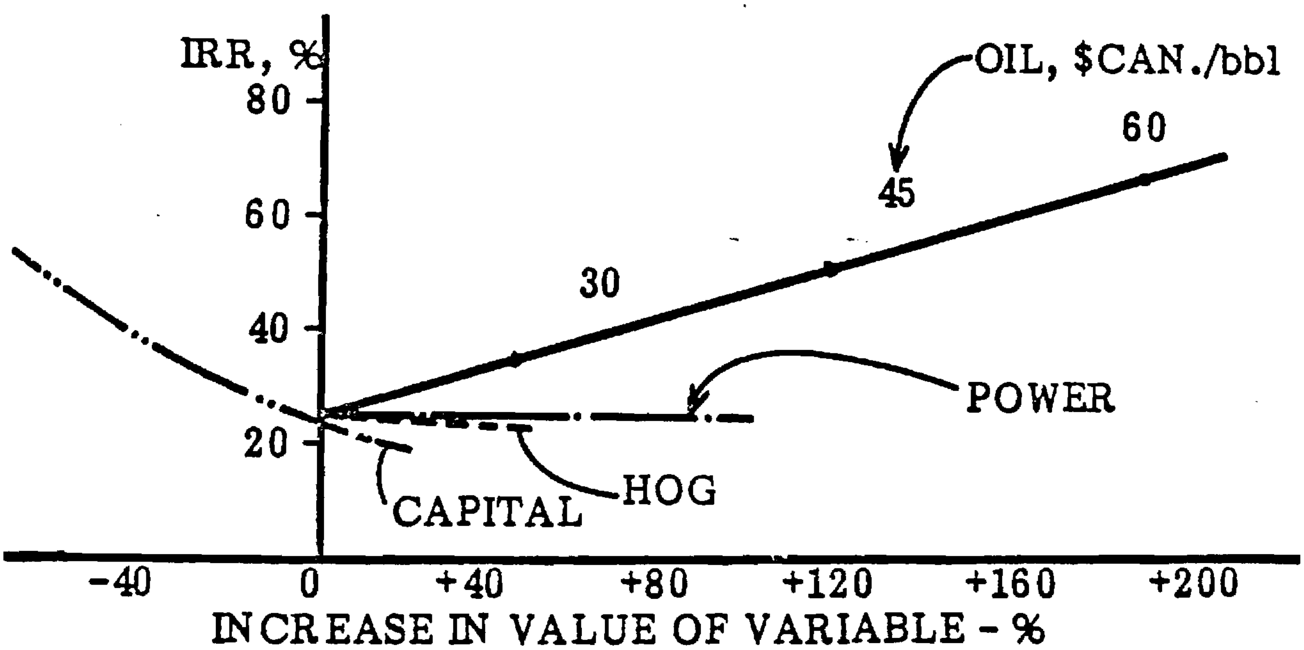

Figure 14 Sensitivity analysis of internal rate of return for retrofit rotary dryer.